Feeding and management strategies for draught animals in sub-Saharan Africa

Centre for Tropical
Veterinary Medicine
Easter Bush
Roslin, Midlothian
EH25 9RG

Project Leader:
R.Anne Pearson

Final Technical Report - R5198 - ODA Livestock Production Programme - April 1996

ACKNOWLEDGEMENTS

To ODA for funding the project.

The collaboration of various organisations, and their staff, in different parts of this project was very much appreciated and is gratefully acknowledged particularly that of the International Livestock Research Institute (ILRI) in Niger, SPANA/SPA and the Institut Agronomique et Veterinaire (IAV) in Morocco, the Ecole Superieure d'Agriculture in Tunisia, the Department of Veterinary Clinical Studies (VCS) at the University of Edinburgh and the Department of Animal Science at Cornell University.

The additional financial support to the project from the International Donkey Protection Trust (IDPT) for purchase of a portable weighing machine, and the University of Edinburgh and the British Veterinary Association, Animal Welfare Fund for studentships was gratefully appreciated.

Executive Summary

The purpose of the project was to produce information on working animals which can be used by research and extension organisations in developing countries as the basis of advice to farmers in Africa. Research activities have been undertaken at CTVM in Edinburgh, in Niger, Nigeria, Morocco, Tunisia and Zimbabwe in collaboration with local and international research organisations.

The energy requirements and nutrient supply from food intake and body reserves of draught oxen working on sandy soils under hot conditions, and the relationship of these factors with work output, were investigated in semi-arid areas in West Africa. From the information obtained recommendations have been proposed on the feeding and management of draught oxen in the semi-arid zone (CTVM input to collaborative CTVM/ILRI project).

Technical assistance was given to R6166 (EMC X0257), 'The effects of feed quality and time of access to feed on feeding behaviour and nutrient intake of tropical cattle and buffalo'. Experimental methods for overseas work were established in two experiments at CTVM.

The effects of soil condition on energy expenditure of working oxen were quantified in experiments in Nigeria and at CTVM.

Energy requirements of working equids were studied in donkeys in Tunisia and ponies and donkeys at CTVM. Comparative studies at CTVM revealed little difference in efficiency of carrying loads between donkeys and ponies. Weight, volume and balance of the load had significant effects on energy cost of carrying per unit of applied load.

In Morocco live weight and body measurements of 516 working donkeys were determined. From these data formulae were developed to enable body weight to be estimated from girth and length measurements in African donkeys used for work. A body condition scoring system was also developed.

In experiments at CTVM the relationship between level of food intake, gastro-intestinal transit time and feed digestibility were investigated in donkeys and to understand how equids cope with these feeds. Results suggest that where the food resource is limited, the donkey, like the ruminant, will have an advantage, but where there are unlimited food supplies, the horse can compensate for reduced digestive efficiency by consuming and processing more food.

The feasibility of using an *in vitro* gas production technique with faeces as an inoculant to assess tropical forage quality for equids was investigated. Feedstuffs were successfully ranked according to their relative *in vivo* digestibilities using the technique with both caecal and faecal inocula. Results suggest the technique would be useful to rank forages for equids in tropical farming systems.

A survey of the role and management of donkeys in semi-arid zones was undertaken in Zimbabwe. Findings suggest that interventions need to focus on nutrition, health, reproduction and the availability of more appropriate implements.

Some of this information will be incorporated directly into dissemination materials (a feeding manual of oxen and a pictorial guide to size and body condition of donkeys). Other information will be used as a foundation for further studies. Use of this information as a basis of advice to farmers and incorporation of the recommendations into existing farming systems in Africa and elsewhere, will enable farmers to make more efficient use of their draught animals.

Background

In agriculture there are three main sources of power, human, animal and mechanical. In most developing countries, human and animal power still predominate and are likely to continue to do so for some time yet. There are at least 400 million animals providing draught power on third world farms. Undernutrition and disease are major constraints to increasing the supply of draught animal power. Reductions in the work output of individual draught animals can lead to (a) problems of reduced crop yields due to poor timeliness or a reduction in the area cropped, (b) increased demand for draught animals and hence animal feed to meet farm power needs, (c) increased demand for human labour to replace failing animal power. This project aimed to address the following needs:

The need to maintain well-nourished healthy draught animals fit for work
- The need to improve the quality of life of farming families, particularly women and children.
- The need to use animal and feed resources in an efficient, sustainable way, minimising the impact on the environment.

Demand for the project was identified from personal contacts with farmers, extension agents, in-country scientists, veterinarians, development organisations and CTVM post-graduate students. Unfortunately information from other ODA supported projects in-country was not accessible. Contacts were made through a variety of means: informal discussions during in-country visits, discussions at conferences and formal meetings overseas, through correspondence, and telephone calls from previously established in-contacts in-country.

Research on the nutrition of draught ruminants builds on ODA funded research previously undertaken by CTVM staff (see Pearson, Lawrence and Smith, 1996). Research on the working equid was undertaken to begin to meet the demand for information on the feeding and management of donkeys and horses coming from farmers in sub-Saharan Africa.

Reference

Pearson, R.A., Lawrence, P.R. and Smith, A.J. 1996. The Centre for Tropical Veterinary Medicine (CTVM) pulling its weight in the field of draught animal research. *Tropical Animal Health and Production,* **28**, 49-59.

Project Purpose

The purpose of the project was to generate information which can be used by research and extension organisations in developing countries as the basis of advice to be given to farmers on the feeding, management and use of animals to provide draught power in Africa.

Research Activities

1. Feeding and working strategies for draught oxen in semi-arid zones

The energy requirements of draught oxen working on sandy soils under hot conditions, the nutrient supply to draught oxen for maintenance and work through intake of feeds and through the mobilisation of body reserves, and the relation of these factors with work output, have been investigated in semi-arid areas in West Africa (CTVM input to collaborative CTVM/ILRI project).

Four experiments were conducted in Niger with ILRI at the ICRISAT Sahelian Centre in Sadore. Experiment 1 investigated the energy costs of oxen working on sandy soils of different consistencies. Experiments 2 and 3 were designed to establish the effect of work on intake, digestibility and rate of passage of millet stover in the digestive tract. Experiment 4 looked at the effect of body condition prior to 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.

CTVM input to this collaborative project included the design, planning and supervision of the experimental studies, provision and maintenance of the some of the equipment used and assistance in the data analysis and production of dissemination materials. Experimental details, results and discussion of scientific outputs are given in Appendix 1 of this report.

2. Time of access to feed on feeding behaviour of draught animals

Two experiments were carried out at CTVM.. The first experiment was designed to study cattle, donkeys and ponies given three different times of access to pasture (24, 8 and 5 hours). The second investigated the effect of feed quality on feeding behaviour and food intake of cattle, horses and donkeys when time of access to feed was limited to 8 hours per day. A double label marker method using chromium and indigestible acid detergent fibre or acid detergent lignin to estimate dry matter intake from the pasture was tested as well as a telemetric bite meter to record feeding behaviour.

3. The effect of soil condition on energy expenditure of working oxen in sub-humid zones

The effects of soil condition on energy expenditure of working oxen have been quantified in experiments in Nigeria and at CTVM. Experimental details, results and discussion of scientific outputs are given in Appendix 2 of this report.

4. Energy requirements of working equids

a) In 1993 the efficiency with which horses of smaller size (about 175 - 230 kg) use energy for work, when pulling loads was determined at CTVM as well as the energy costs of walking. Five ponies pulled loads of 5, 10 and 15 kg df/100 kg live weight using a breastband harness when walking on a treadmill at a speed of 1.1 m/s. The rate of energy expenditure was determined by indirect calorimetry and the rate of work was calculated from draught force and speed of working. See Appendix 3 for experimental details and results.

b) A collaborative study between the CTVM and University of Edinburgh Department of Veterinary Clinical Studies (VCS) has continued to investigate the energy needs of freeliving and working ponies. In 1993 the energy used by ponies to move over different terrain was measured using a portable breath-by-breath oxygen analyser (the Oxylog).

c) In 1994 the energy cost of carrying loads was studied using 3 male donkeys in Tunisia. Donkeys wore the local pack saddle and carried loads equivalent to 40% of live weight, whilst walking on a 400m undulating track. Total distance walked per day was 6 km in the morning and 4 km in the afternoon. Donkeys undergoing work alternately wore the modified Oxylog during the morning or afternoon session. Standing metabolic rate was also recorded at the start and end of the working day for 20 minutes. See Appendix 3 for details of experimental methods results and discussion of the scientific outputs.

d) In 1995/1996 comparative studies were made at CTVM of the efficiency of carrying loads in donkeys and ponies. The effects of weight and volume of the load on the energy cost of carrying per unit of applied load were also determined using three donkeys and three ponies trained to walk on a treadmill. Energy expenditure was determined using indirect open circuit calorimetry.

5. A simple method to predict live weight and a body condition scoring system for working donkeys in North Africa

Live weight and body measurements were taken of 516 donkeys in the souks around Morocco. All the donkeys had been used to transport goods to and from the markets. Heart girth, umbilical girth, length, height, cannon bone circumference, age, sex and live weight were recorded. A portable electronic weighing machine (Ruddweigh, NSW, Australia) was used to record live weight. A body condition scoring system was also developed. Full experimental details, results and discussion of scientific outputs are given in Appendix 4 of this report.

6. Intake and digestion of fibre diets by donkeys and horses

The relationship between level of food intake, gastro-intestinal transit time and feed digestibility were investigated in ponies and donkeys when given a low fibre forage diet (alfalfa) and a high fibre forage diet (oat straw). The equids were given four treatments in turn: high fibre *ad libitum*, low fibre *ad libitum*, high fibre, restricted (75 % of *ad libitum* intake) and low fibre, restricted. The digestibility of dry matter, organic matter, gross energy, crude protein, acid detergent fibre and neutral detergent fibre were estimated. The rate of passage of the diets through the gastro-intestinal tract was measured using Cr-mordented fibre and Co-EDTA according to Pearson and Merritt, (1991).

Reference

Pearson, R.A. and Merritt, J.B. 1991. Intake, digestion and gastro intestinal transit time in resting donkeys and ponies and exercised donkeys given *ad libitum* hay and straw diets. *Equine Veterinary Journal*, **23**, 339-343.

7. Development of simple ways to assess nutritive value of feeds for equids

The feasibility of using an *in vitro* gas production technique with faeces as an inoculant to assess tropical forage quality for equids was investigated. Two studies were undertaken. Naked oats and four forages (grass pellets, alfalfa hay, oat straw, and millet stover), all of known *in vivo* digestibility were incubated *in vitro* with either a faecal or a caecal digesta inoculum. Full experimental details and results are given in Appendix 5.

8. The role of the working donkey in smallholder farming systems in semi-arid zones

Due to circumstances beyond our control the planned study of the role and management of donkeys in semi-arid zones could not take place in Niger. So instead work was undertaken in Guruve District, North Zimbabwe. Data was collected at five animal health centres. Fifty eight donkey owners (17% female, 82% male) were interviewed in the Shona language, and 196 donkeys were examined for health, and live weight and age were also determined.

Outputs

1. Feeding and working strategies for draught oxen in semi-arid zones

Scientific outputs are reported in Appendix 1. The following are the recommendations on feeding and working strategies which have been proposed as a result of the research work. The study suggested that no drastic changes in the way farmers manage their oxen are required, but that by modifying their management practices a little farmers can get more work from their animals:

- Recommendations on how to feed oxen better in the semi-arid zones focus on making better use of local roughages by supplementing them with brans, oilseed cakes and hays. Feed is plentiful during the rainy season and it is suggested that farmers must do more to conserve this feed for use during the dry season. Animal traction can contribute a great deal to this end by facilitating the harvest and transport of forages.

- The study found that the amount of work draught oxen can do is more dependent on their body weight than on their body condition, so farmers should select large-framed animals for work. Trying to keep oxen in good condition during the dry season was largely a waste of feed; the better the initial body condition of the oxen, the more weight they lost when working. A better strategy was to feed the oxen well after the working period as they rapidly regain live weight lost through compensatory growth.

- Observations suggested that on a scale from 1 (emaciated) to 9 (obese) a body condition score of 2.5 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 not too fat neither 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 over 6 is unlikely to be profitable as far as feeding for work performance is concerned.

- In semi-arid areas, the growing season is short so farmers need their draught animals to work hard from the start. Trials showed that power output increased as the work season progressed despite live weight losses incurred by oxen. The lower power output observed during the first days of work was attributed to oxen undergoing an adaptation to work after a long 'layoff' period. The increase in power output during the following weeks was due to the improved fitness of the oxen. The results showed the benefit of regular work. Farmers would get more work from their oxen at the start of the cultivation season by having them in work during the dry season. This could be achieved by making use of the oxen for carting during the dry season.

- Heat stress inhibited work performance. Power output was greatest when air temperature was lowest. It was recommended that farmers work their animals in the coolest periods of the day, allowing them to rest and providing water between bouts of work. The provision of shade during resting periods was also worthwhile, increasing power output in subsequent work sessions. Specific recommendations were that the number of hours worked per day should be split between morning and afternoon sessions. Oxen should be worked for no more than 6 hours per day, 3 to 4 h in the morning between 06:00 or 07:00 to 09:00 or 10:00 hours and for 2 to 3 h in the afternoon from 16:00 or 17:00 to 18:00 or 19:00 hours. Oxen should be rested after each hour of work for about 10 min. and offered water to help them cool down.

- It was recommended that if paired animals are of different sizes or cows are used with oxen, the animals should be teamed so that the smaller, lighter animal is on the unploughed soil, the larger animal walking in the furrow. This is based on findings here and in Nigeria (see output 3) that the energy cost of walking even on light sandy soils was higher for the animal walking on the ploughed soil than that on the unploughed land.

2. Time of access to feed on feeding behaviour of draught animals

Technical assistance to project R6166, enabled a bite meter to be tested and methodologies to be checked in two projects at CTVM. telemetric bite meter systems proved to be cumbersome to use in rangeland situations. Data logger recording systems proved easier to use and have now been adopted. Of the methodologies tested, preliminary findings suggest that acid detergent lignin is the most practical marker method to adopt to estimate digestibility at pasture. The work is continuing in project R6166.

Table 1: The speed of walking and energy cost of walking of Bunaji bulls on soils of different consistencies in the sub-humid zone of Nigeria (Dijkman and Lawrence, 1996)

Soil	n	Speed (m/s)	Energy cost of walking (J/m/kg)
Unploughed upland	8	0.97	1.47
Ploughed upland	6	0.83	2.87
Unploughed dry fadama	6	0.87	1.76
Ploughed dry fadama	6	0.74	3.76
Unploughed wet fadama	6	0.80	3.30
Ploughed wet fadama	6	0.65	8.58
s.e.m., n = 8 (32df)		0.07	0.22
s.e.m., n = 6 (32df)		0.06	0.26

n = number of animals

3. The effect of soil condition on energy expenditure of working oxen in sub-humid zones

Energy cost of walking can vary from 1.47 J/m/kg on firm level earth to 8.58 J/m/kg on ploughed waterlogged clay (see Table 1 and Appendix 2 for details). Net mechanical efficiency (about 31.4%) is unaffected by ground surface.

4. Energy requirements of working equids

a) In small horses at CTVM the net energy costs of walking on a treadmill were consistently between 1.00 and 1.46 J/m/kg (Table 2 and Appendix 3). Efficiency of doing work described as the work done/energy expended in work was as reported in Table 3. The difference in energy efficiency for work between ponies was small and not significant.

Table 2: Mean (s.e.) energy costs of standing and of walking on a treadmill by five Shetland ponies (n=13). Results are expressed per kg liveweight

	Energy used		Energy costs of walking			
Animal	For standing (W/kg) mean	s.e.	Total cost (W/kg) mean	s.e.	Unit cost (J/m/kg) mean	
Silver	1.91^{a}	0.11	3.38	0.08	.46^{a}	0.07
Pawnee	2.16^{b}	0.10	3.32	0.07	15^{b}	
Deil	1.49^{c}	0.07	2.66	0.04	1.17^{b}	
Comanche	1.86^{a}	0.06	2.86	0.04	1.00^{b}	
Apache	2.28^{b}	0.08	3.33	0.07	1.05^{b}	

a,b,c Within columns means followed by different superscripts are significantly different (P<0.05)

Table 3: Energy costs of pulling loads singly on a treadmill and the efficiency with which five Shetland ponies used energy for work at three different loads

Load kgdf/100 kg liveweight	n	Unit energy cost of pulling (J/m/kg load (pulled) mean	s.e	Efficiency of working work done/ energy used (%)	s.e.
5	25	33.12^{a}	0.70	33	0.7
10	20	29.11^{b}	0.84	34	0.9
15	20	31.36^{b}	0.74	30	0.5

a,b, Within columns means followed by different superscripts are significantly different (P<0.05)

A comparison of the energy costs of walking from treadmill studies between equids indicated that donkeys have the lowest energy costs of walking (0.97 J/m/kg, Dijkman, 1992) followed by Shetland ponies (1.06 J/m/kg, present study). and then horses (1.6 J/m/kg Hoffman *et al.*, 1967). These figures are marginally lower than those measured in treadmill studies of cattle and buffalo. The results for energy costs of pulling (Table 3 and Appendix 3) showed that the efficiency with which small horses use energy for work is similar to that found in other draught animals (cattle 0.30; large horses 0.35; buffalo 0.36; donkeys 0.37).

b) Field measurements of the effects of ground surface on the energy costs of walking by ponies gave the following results: The energy costs of walking were 2.5 J/m/kg on hard level earth, 5.8 J/m/kg on ploughed clay soil and 5.9 and 7.3 J/m/kg uphill on grass slopes at gradients of 2.2% and 10% respectively. Net mechanical efficiency (about 32%) was unaffected by ground surface.

c) Field observations of energy costs of walking and carrying loads in Tunisia are given in Table 4. Further details are given in Appendix 3 of this report.

Table 4: Mean (s.e.) unit energy costs of walking and of carrying loads over undulating sandy tracks by three donkeys in Tunisia (n=9)

	Unit energy cost of		
Animal	Walking (J/m/kg liveweight) mean	Carrying loads (J/m/kg load carried) mean	s.e.m.
1	1.35	2.50	0.07
2	1.40	2.47	0.11
3	.36	2.06	0.11

The extra energy used for carrying 40kg/100kg live weight by the donkeys (2.34 J/m/kg carried) was more than that seen in treadmill studies of donkeys carrying lighter loads on the level (1.1 J/m/kg carried, Dijkman, 1992), but similar to observations of donkeys carrying loads on gradual slopes or undulating ground (2.7 - 3.3 J/m/kg, Yousef and Dill, 1969; Yousef *et al.*, 1972; Dijkman, 1992). Loads were balanced. Energy costs of carrying increased by two to three fold if the load was unbalanced across the animal's back. The results have provided information to allow prediction of the energy needs of pack donkeys to be made.

References

Dijkman, J.T. 1992. A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads. *Animal Production*, **54**, 153-156.

Hoffman,, L. Klippel, W and Schiemann, R.1967. Untersuchungen uber den Energieumsatz beim pferd unter besonderer Berucksichtigung der Horizontal bewegung. *Archives Tierernaehr*, **17**, 441-452.

Yousef, M.J. and Dill, D.B. 1969. Energy expenditure in desert walks:man and burro, *Equus asinus*. *Journal of Applied Physiology*, 27, 681-683.

Yousef, M.J., Dill, D.B. and Freeland, D.V. 1972. Energetic cost of grade walking in man and burro, *Equus asinus*: desert and mountain. *Journal of Applied Physiology*, 33, 337-340.

d) Comparative studies revealed little difference in efficiency of carrying loads between donkeys and ponies. Weight, and balance of the load had greater effect on the energy cost of carrying per unit of applied load (Table 5).

Preliminary results show that the greater the weight carried the more efficient is the energy cost of carrying the applied load. Loads varied from 13 to 27 kg/100 kg live weight. Figures for heavier loads were not taken. Little difference was seen in energy cost of carrying bulky as opposed to dense loads, provided the loads were evenly distributed across the animal's back. Poor balance of the load increased the energy cost of carrying, in this case by two to three fold.

Table 5: Mean energy costs (J/m/kg carried) of carrying dense (lead short) and bulky (straw bales) loads by three ponies and three donkeys (n = 3)

	Dense Load			Bulky Load		
Load kg/100kg liveweight	Heavy 27	Medium 20	Light 13	Heavy 27	Medium 20	Light 13
Ponies 1	2.86	4.30	6.01	2.86	3.64	5.97
2	2.77	3.45	6.50	3.95	3.60	4.27
3	4.40	3.47	2.94	5.23	3.82	7.22
Mean	3.34	3.74	5.15	4.01	3.69	5.82
Donkeys 1	4.83	7.46	12.33	2.93	3.19	4.77
2	1.90	2.55	3.05	3.11	3.05	4.31
3	2.51	2.06	3.85	2.79	4.11	7.47
Mean	3.08	4.02	6.41	2.94	3.45	5.52

5. A simple method to predict live weight and a body condition scoring system for working donkeys in North Africa

There were few donkeys over 12 years of age. The best equation with only one variable for predicting live weight of adult donkeys weighing from 74 - 252 kg was live weight (kg) = heart girth (cm) $^{2.64}$/2188. The inclusion of two variables improved the prediction marginally, but the addition of further variables gave little further improvement. The best

A GUIDE TO THE BODY CONDITION SCORING OF DONKEYS

SCORE		DESCRIPTION
1	Very thin (emaciated)	Animal markedly emaciated, condemned. Bone structure easily seen over body. Little muscle present, animal weak, lethargic.
2	thin	Animal emaciated, individual spinous processes, ribs, tuber coxae, tuber ischii and scapular spine all prominent, sharply defined. Some muscle development, neck thin, prominent withers, shoulders sharply angular.
3	less thin	Vertebral column prominent and individual spinous process can be felt (palpated), little fat, but superspinous musculature over spinous processes apparent.. Ribs, tuber ischii and tuber coxae prominent, loin area and rump concave, little muscle or fat covering over withers and shoulders.
4	less than moderate	Vertebral column visible. Tuber ischii palpable but not visible, tuber coxae rounded but visible. Rump flat rather than concave, ribs palpable but not obvious, withers, shoulders, neck with some muscle and fat cover, with scapular less clearly defined.
5	moderate	Superspinous muscles developed and readily apparent. Can palpate vertebral column, tuber coxae rounded, rump rounded, convex, tuber ischii not visible, some fat palpable in pectoral region and at base of neck, can palpate ribs, but not visible.
6	more than moderate	Cannot palpate spinous processes, easily, back becoming flat well covered. Rump convex and well muscled. Some fat palpable on neck, base of neck and pectoral region. Neck filled into shoulder, tuber coxae just visible.
7	less fat	Back flat, cannot palpate spinous processes. Tuber coxae just visible. Fat on neck and pectoral region beginning to expand over ribs. Flanks filling, neck thickening.
8	fat	Animal appears well covered with body rounded with fat and bones not discernible. Flanks filled, broad back.
9	very fat (obese)	Bones buried in fat. Back broad or flat, in some cases crease down back. Large accumulations of fat on neck, over pectoral area and ribs, flank filled with fat.

Notes: 1-3 frame obvious 4-6 frame and covering balanced 7-9 frame not as obvious as covering.

Individual donkeys can deposit their body fat in different areas of the body, so the individual neck shoulders, ribs, rump, and flank condition should be assessed and combined to give an overall condition score.

prediction equation for adult donkeys was live weight (kg) = (heart girth $[\mathrm{cm}]^{2.12}$ x length $[\mathrm{cm}]^{0.688}$)/380. For donkeys under three years of age, weighing 52 to 128 kg, the best prediction equation was live weight (kg) = (umbilical girth$[\mathrm{cm}]^{1.41}$ x length $[\mathrm{cm}]^{1.09}$)/1000. Other liveweight prediction equations for donkeys and horses were tested on the data and tended to overestimate the weight of these working donkeys. A subjective method for assessing the body condition of the donkeys was developed using a scale from 1 (emaciated) to 9 (obese). This is shown in Figure 1.

6. Intake and digestion of fibre diets by donkeys and horses

All animals digested the components of the high fibre diets less well than those of the low fibre. Donkeys digested fibre more effectively than the horses. However on *ad libitum* feeding ponies ate about 30 % more than the donkeys per kg live weight Preliminary results are given in Table 6. These results suggest that where the food resource is limited, the donkey, like the ruminant, would have an advantage, but where there are unlimited food supplies, the horse can compensate for reduced digestive efficiency by consuming and processing more food.

Table 6: Mean (± se) apparent digestibility of organic matter (OM), gross energy (GE), crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) by ponies and donkeys on four different diets - *ad libitum* alfalfa (*ad lib*-ALF) *ad libitum* oat straw (*ad lib*-OS), restricted (75% of *ad libitum*) alfalfa, (rest-ALF) restricted oat straw (rest-OS) (n=4).

	Food intake g/kg live-wt	**OM**	**GE**	**CP**	**ADF**	**NDF**
Ad lib - ALF						
Ponies	39.33	0.58±0.02	0.54±0.03	0.67±0.01	0.36±0.02	0.37±0.03
Donkeys	27.48	0.65±0.02	0.60±0.02	0.74±0.02	0.48±0.04	0.48±0.02
Ad lib - OS						
Ponies	23.69	0.46±0.05	0.44±0.05	0.09±0.14	0.46±0.07	0.46±0.05
Donkeys	14.73	0.50±0.02	0.47±0.03	0.14±0.04	0.50±0.03	0.50±0.01
Rest - ALF						
Ponies		0.50±0.05	0.45±0.05	0.61±0.05	0.26±0.06	0.26±0.07
Donkeys		0.64±0.01	0.61±0.01	0.74±0.01	0.45±0.02	0.49±0.05
Rest - OS						
Ponies		0.42±0.01	0.38±0.02		0.41±0.03	0.43±0.01
Donkeys		0.48±0.03	0.42±0.03		0.47±0.03	0.50±0.02

7. Development of simple ways to assess nutritive value of feeds for equids

In the two studies total *in vitro* gas production was highly correlated with the proportion of feedstuff degraded ($r^2 = 0.84$, $P<0.001$). For all feedstuffs studied, cumulative gas production profiles and total gas production were similar when using donkey or pony faeces as an inoculum source ($r^2 = 0.99$). Cumulative gas production was also similar when comparing donkey faeces with caecal fluid ($r^2 = 0.95$). However total gas production (ml) after 120 h was greater with donkey faecal compared to caecal inoculum for the forages (Table 7). Full details of results are given in Appendix 5.

Table 7: Total gas production from 0.75g feed substrate after a 72-hour (study 1) or 120-hour (study 2) incubation period.

Total Gas Production (ml / 0.75g feed DM)		Naked Oats	Grass Pellets	Alfalfa Hay	Oat Straw	Millet Stover
Study 1 (t72)	Donkey Faeces	214 ± 6.6	144 ± 4.3	134 ± 2.5	127 ± 3.8	89 ± 1.7
	Pony Faeces	215 ± 4.2	143 ± 3.8	137 ± 2.2	128 ± 4.2	86 ± 2.0
	Significance	NS	NS	NS	NS	NS
Study 2 (t120)	Donkey Faeces	225 ± 6.4	170 ± 4.1	148 ± 2.8	139 ± 2.9	107 ± 4.5
	Pony Caecal Fluid	220 ± 7.1	144 ± 2.6	130 ± 3.5	119 ± 2.2	81 ± 3.2
	Significance	NS	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$

Conclusions from the *in vitro* study were

- Feedstuffs were successfully ranked acording to their relative *in vivo* digestibilities using the gas production technique with both caecal and faecal inocula. This suggests the technique could provide a useful means of assessing nutritive value of forages in tropical husbandry systems.

- Little difference appears to exist in *in vitro* fermentation characteristics between pony and donkey faeces derived from animals on a similar diet.

- Gas production and DM degradation values were higher for the more fibrous feedstuffs when using faecal inoculum in comparison to caecal fluid. This suggests an increased ability of the faecal microbes to digest fibrous feed components.

  The ruminant-based equations of France *et al.* (1993) for the prediction of *in-vivo* digestibility proved inadequate in this study. New or revised models specifically designed for use with *in-vitro* fermentation data from equids may be required.

8. The role of the working donkey in smallholder farming systems in semi-arid zones

Mean number of donkeys owned was 3 (range 1-10). Most of the farmers also owned other livestock, cattle, goats and sheep and poultry. Average area of land cultivated was 4.2ha (range 0.5 - 25ha). All respondents came from male headed households. 36% of those interviewed relied solely on the farm for their livelihood, the others had outside income. The donkeys were managed by the whole family, but owned by the head of the household. Donkeys were relatively recent acquisitions, 60% of farmers had not always kept donkeys and most had only kept them for 1 to 35 years.

The average age of a donkey at the start of work was 2.6 years, with a working life of 16 years. Donkeys were kraaled at night sometimes with the cattle. 47% of the farmers questioned did not castrate their donkeys. Castration was usually done at 2 years to stop the donkey becoming a nuisance or straying. Health care was practised by about half the farmers, with 31% making use of traditional methods. Feet and teeth were reputed to be checked by 38 % of the farmers questioned with about 64% of donkeys needing treatment in the past. Breeding of female donkeys was not planned and most foals were born in July/August. Foaling interval varied widely from 1-12 years.. Generally weaning was left to occur naturally. 64% of farmers supplemented their donkeys feed intake from grazing when and where possible with crop residues, local supplements and melons. Water was offered once daily by half the farmers and up to once per week by others. 10% of farmers left their donkeys to independently find water.

Donkeys were brought locally within the area. Some hiring took place to make up teams. Donkeys were mainly kept for domestic and commercial use, both carting and carrying loads. Half the farmers used the animals for ploughing in the season, generally in teams of four to an ox plough. Over 60% of farmers used yokes to harness their donkeys, despite legislation against this practice, with only 30% using breastbands. The remaining farmers used a combination of yoke (upside down) with breastbands. Sores were only thought to be a problem by 33% of farmers especially in the wet season. Donkeys carried weights ranging from 6 to 160 kg with a mean load of 50 kg. Grain, water and firewood were the most common loads carried. Most donkeys were used for transport 3-4 times a week(range 1-7), more frequently in the wet than the dry season.

Management constraints identified by farmers were nutrition and watering, sores caused by poor harnessing and unplanned breeding. Recommendations from the study were that interventions need to focus on nutrition, health, reproduction and the availability of more appropriate implements.

Contribution of Outputs

The planned outputs of the project have been achieved and the results and recommendations have been written up for dissemination. Two research papers remain outstanding but are in preparation (one on energy needs for load carrying including practical recommendations, and one on forage intake by equids). These will be finished within the next 3 months. Incorporation of observations and recommendations into existing farming systems will enable farmers in Africa and elsewhere (where applicable), make more efficient use of their draught animals.

Promotional Pathways

The immediate promotional pathways have been and will continue to be through papers in scientific journals and the popular press. The following section lists the articles which have been published or accepted for publication during the course of the project. They are arranged in two parts firstly those resulting from specific research activities and secondly those of a more general nature.

Publications:

a) Specifically from research activities

Cuddeford, D., Pearson, R.A. Archibald, R.F. and Muirhead, R.H. 1995. Digestibility and gastro-intestinal transit time of diets containing different proportions of alfalfa and oat straw fed to thoroughbreds, Shetland ponies, Highland ponies and donkeys. *Animal Science*, **61**, 407-418.

Dijkman, J.T. 1993. The measurement of draught ruminant energy expenditure in the field. PhD Thesis, University of Edinburgh.

Dijkman, J.T. and Lawrence, P.R. 1996. The energy expenditure of cattle and buffaloes walking and working in different soil conditions. *Animal Science* (in press).

Fall, A. 1995. Factors affecting feed intake, energy expenditure and work output of oxen and bulls used for draught purposes in semi-arid West Africa, PhD Thesis, University of Edinburgh.

Kirkhope, R.T.S. and Lowman, R.S. 1996. Use of an *in vitro* gas production technique with faeces as inoculant to assess tropical forage quality for equids. Poster presented at the BSAS Winter Meeting 18-20 March Scarborough. *Animal Science Abstract* (in press).

Mueller, P.J., Hintz, H.F., Pearson, R.A., Lawrence, P.R. and van Soest, P.J. 1994. Voluntary intake of roughage diets by donkeys. In: *Proceedings of the International Colloquium on Working Equines* (eds M.B. Bakkoury and R.A. Prentis), pp.137-148. Actes Editions, Rabat, Morocco.

Pearson, R.A. and Ouassat, M. 1995. Estimation of live weight and a body condition scoring system for working donkeys in Morocco. *Veterinary Record*, **138**, 229-233.

Pearson, R.A. and Smith, D.G. (1994). The effects of work on food intake and ingestive behaviour of draught cattle and buffalo given barley straw. *Animal Production*, **58**, 339-346.

Smith, D.G., Nahuis, A. Archibald, R.F. 1994. A comparison of the energy requirements for work in donkeys, ponies and cattle. In: *Proceedings of the International Colloquium on Working Equines* (eds. M. Bakkoury and R.A. Prentis), pp. 17-22. Actes Editions, Rabat, Morocco.

Smith, D.C., Pearson, R.A. and Campbell, I. 1993. Changes in food intake and ingestive behaviour of draught cattle and buffalo associated with work. *Proceedings of the World Conference on Animal Production*, **2**, 358-359

Thu, N.V., Dong, N.T.K., Preston, T.R. and Pearson, R.A. 1966. Studies on buffalo in the Mekong Delta in Vietnam. *Proceedings of ACIAR/MOET/MAFI Workshop "Exploring Approaches to Research in the Animal Sciences in Vietnam"*, 31 July-3 August 1995.

Thu, N.V., Pearson, R.A., Preston, T.R. and Fajersson, P. 1996. Effect of work crushing sugarcane on pregnancy and lactation in cattle and buffaloes. *Asian Australasian Journal of Animal Science* (in press).

b) General articles and reviews

Lawrence, P.R. and Pearson, R.A. 1993. Experimental methods in draught animal science: The need for standardisation. *In: Human and Draught Animal Power in Crop Production* (eds. D.H. O'Neill, G. Hendriksen), pp. 36-39. Proceedings of the Silsoe Research Institute/CEC/FAO Workshop, 18-22 January 1993, Harare. Printed by FAO, Rome.

Lawrence, P.R. and Pearson, R.A. 1993. Experimental methods in draught animal research. *In: Research for Development of Animal Traction in West Africa. Proceedings of the Fourth Workshop of the West Africa Animal Traction Network,* 9-13 July 1990, Kano, Nigeria (eds P.R. Lawrence, K. Lawrence, J.T. Dijkman and P.H. Starkey) pp. 187-198. West Africa Animal Traction Network and International Livestock Centre for Africa.

Pearson, R.A. 1993. Resource requirements for draught animal power. *In: Animal Production in Developing Countries,* (eds M. Gill, E. Owen, G.E. Pollott and T.L.J. Lawrence), pp. 57-67. Occasional Publication No 16. British Society of Animal Production.

Pearson, R.A. 1994. Draft Animal Power *In: Encyclopaedia of Agricultural Science,* Vol. 1 pp. 613-623 Academic Press, California, USA.

Pearson, R.A. 1995. Management and husbandry of working animals with particular reference to their welfare. *Proceedings of the Cairo International Meeting on Working Animals,* April 13-16 1992, Cairo, Egypt, pp. 65-82.

Pearson, R.A. 1995. Feeding systems for draught ruminants on high forage diets in some African and Asian countries. In: *Recent Developments in the Nutrition of Herbivores,* (eds. M. Journet, E. Grenet, M.H. Farce, M. Thériez, C. Demarquilly), pp 551-567. *Proceedings of the IVth International Symposium on the Nutrition of Herbivores,* INRA Editions, Paris.

Pearson, R.A. 1995. Feeding draught animals for work. *Feed Mix,* **3**, 13-17.

Pearson, R.A., Bakkoury, M., Ouassat, M. 1993. Strategies d'amelioration de l'utilisation des animaux de trait. Association Nationale pour la Production Animale. 22 ème Journees Traction Animale et Developpement Agricole.

Pearson, R.A. and Dijkman, J.T. 1994. Nutritional implications of work in draught animals. *Proceedings of the Nutrition Society,* **53**, 169-179.

Pearson, R.A. and Fall, A. 1993. Research on the nutrition of draught animals. *In: Human and Draught Animal Power in Crop Production* (eds D.H. O'Neill and G. Hendriksen) pp. 60-68. Proceedings of the Silsoe Research Institute/CEC/FAO Workshop, 18-22 January 1993, Harare.

Pearson, R.A., Lawrence, P.R. and Smith, A.J. 1995. The Centre for Tropical Veterinary Medicine (CTVM) pulling its weight in the field of draught animal research. *Tropical Animal Health and Production,* **28**, 49-59.

Pearson, R.A. and Matthewman, R.W. 1994. Technology for rural livelihoods: Lessons from CTVM's draught animal research for the implementation of sustainable development. *In: Technology for Rural Livelihoods; Current issues for Engineers and Social Scientists* pp. 67-72. *Proceedings of a workshop held at the Natural Resources Institute, Chatham* 6-7 September 1994, ODA.

Pearson, R.A. and Smith, A.J. 1994. Improving draught animal management. In: *Improving Animal Traction Technology. Proceedings of 1st workshop of the Animal Traction Network for Eastern and Southern Africa (ATNESA)* (eds P. Starkey, E. Mwenya and J. Stares) pp. 122-129. Technical Centre for Agricultural and Research Cooperation (CTA) Wageningen, The Netherlands.

Internal Reports:

CTVM Annual Report 1993/1994.

Fall, A., Pearson, R.A., Lawrence, P.R. and Fernández-Rivera, S. 1995. Feeding and working strategies for oxen used for draught purposes in semi-arid West Africa. Centre for Tropical Veterinary Medicine/ International Livestock Research Institute Final Project Report-(Internal circulation only, not for general publication).

MSc theses

Alford, R.J. 1994. Working and feeding strategies of draught N'Dama oxen in a Gambian village. MSc thesis, University of Edinburgh.

Krause, P. 1993. An assessment of suitable harnessing techniques for donkeys used to draw carts. MSc thesis, University of Edinburgh.

Morriss, C.J. 1995. A baseline study of donkey management, health, reproduction and uses in Mashonaland central, North Zimbabwe. MSc thesis, University of Edinburgh.

Mumbi, M.D. 1994. Integration of animal traction into the farming systems of sub-Saharan Africa - a case study of Northern Zambia. MSc thesis, University of Edinburgh.

Nahuis, A.A. G. 1993. Energy cost of walking and pulling loads at different draft forces by Shetland ponies. MSc thesis, University of Edinburgh.

Other Dissemination of Results and Plans for Further Dissemination:

The scientific information on feeding and management of draught oxen in the semi-arid zone was submitted and accepted as three research papers in Animal Science (see Appendix 1) The results with practical recommendations will be also published as a joint CTVM/ILRI Publication. Plans are being made to prepare other extension materials in collaboration with ILRI.

Information on the energy requirements of draught cattle has been incorporated into a manual 'Feeding standards for cattle used for work' by P.R. Lawrence, which is currently in draft form and should be published in 1996 if funding is secured.

Six issues of '*Draught Animal News*' a biannual publication were produced and funded from the project. Results of the present project have been disseminated in this publication and will be in future issues, in addition to information from elsewhere in the world. *Draught Animal News* has funding for the next three years from ODA.

The internet: The CTVM has 'pages' on the World Wide Web in which the research on this and other CTVM animal production projects funded by ODA will continue to be publicised (http:/vet.ed.ac.uk/ctvm).

Informal dissemination through personal contacts, papers at small local workshops (this year in Chile, Mexico) and formal teaching on courses in UK (at CTVM), Germany, Sweden and Vietnam have taken place during the lifetime of the project and it is anticipated that these promotional pathways will continue to operate during the next few years.

A book on Draught Animals in the Macmillan/CTA Tropical Agriculture Series is planned and funding is now available.

A pictorial manual on body condition and live weight estimation of African donkeys is envisaged. Some photographs are still required for completion and funds for dissemination are needed.

Follow-up indicated/planned:

Research:

Output 1: Recommendations on feeding and management of cattle in semi arid areas need to be applied and tested on-farm.

Output 2: The ODA funded project (R6166, EMC X0257) 'The effects of feed quality and time of access to feed on feeding behaviour and nutrient intake of tropical cattle and buffaloes', continues for another year.

Output 3: Validation of feeding standards for working cattle is planned and some funding is available from ODA for work in South Africa.

Output 5: The live weight estimation and body condition scoring system is being used and tested on working donkeys as part of a project in Zimbabwe (R5926).

Output 4,6,7,8: There is a need for research on feeding and management of working donkeys including the nutritive value of feeds for donkeys to continue so that the increased demand for information on feeding and management of donkeys by farmers in Sub-Saharan Africa can be met. This could in the future provide enough material for the production of a manual on feeding standards and guidelines on health care of these animals.

Dissemination:

See previous section

Name and signature of author of this report.

Anne Pearson

Dr R. Anne Pearson

Appendixes 1 5

Appendix 1 - Drafts accepted for publication in Animal Science with minor modifications

Nutrition of draught oxen in semi-arid West Africa. I. Energy expenditure by oxen working on soils of different consistencies

A. Fall[1], R.A. Pearson[1] and P. R. Lawrence[2+]

[1]CTVM, University of Edinburgh, Easter Bush, Roslin, Midlothian EH25 9RG, UK

[2]International Livestock Research Institute, ICRISAT Sahelian Centre, BP 12404, Niamey, Niger

Abstract

The Oxylog, a portable breath by breath gas analyser, was used on 7 animals to determine standing metabolic rate, energy cost of walking on soils of different consistencies, and efficiency of work, ploughing and carting. The average standing metabolic rate of animals was 5.63 (s.e. 0.12) W/kg $M^{0.75}$. *The consistency of the soil on which animals worked had a marked effect on their energy cost of walking which was 1.59 (s.e. 0.069) on unploughed soil, 2.15 (s.e. 0.084) on ploughed soil and 1.0 (s.e. 0.10) J/m/kg live weight on laterite tracks. The efficiency of ploughing sandy soils (i.e. ratio of work done to energy used for work,) was 0.32 and was not significantly different from the efficiency of carting with different loads. The efficiency of doing work was not influenced by the type of work performed, the draught force exerted or the walking speed.*

Key words: *energy expenditure, draught oxen, work efficiency*

Introduction

Draught animal power (DAP) was introduced in sub-Saharan Africa during the last 70 years and its use is spreading (Starkey, 1994; Panin and Ellis, 1994). However, the contribution of draught animals to the power requirements for agriculture is still limited. Agricultural production in this region continues to rely primarily on human power. Statistics in 1987 suggested that 89% of power was provided by humans while draught animals supplied only 10% of the farm power input (FAO, 1987). There is a need to promote DAP 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 in these areas. The low and erratic rainfall regime constrains land preparation and timely planting at the onset of the rainy season. In these situations

---

[+] Present address: Centre for Agriculture in the Tropics and Subtropics. Institute of Animal Production, Department of Animal Nutrition and Aquaculture. Universität Hohenheim (480), D-7093, Stuttgart, Germany

DAP 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. Adequate feeding to meet the nutrient requirements of draught animals is a major constraint in semi-arid areas, because food is scarce and of poor quality during many months in the year. In these areas there is a need for a rationale planning of the feeding of draught animals to supply sufficient DAP for crop production. This requires information on the seasonal availability and the nutritive value of existing food resources, the utilisation of these feeds by draught animals and the nutrient requirements for work. Information on the energy requirements for work and food utilisation of draught animals in semi-arid West Africa is limited. However, the recent adaptation of portable equipment to measure oxygen consumption (Lawrence, Pearson and Dijkman, 1991) can contribute greatly to the knowledge of the energy expenditure of animals performing common farm operations.

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 sub-humid 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.

Material and methods

Animals and feeding

This experiment was conducted from October to November 1994 at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Centre at Sadore, Niger. Seven Diali (*Bos indicus)* cattle, average live weight 367 kg, aged 5-7 years, were used in the study. The animals were fed to about maintenance on natural pastures supplemented with wheat bran and a mineral mixture. The animals had access to water *ad libitum* during the periods that 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% when work took place in the afternoon.

Experimental methods

Oxygen consumption was measured using the Oxylog, a portable breath by breath analyser. This instrument (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).

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 flowmeter (Humfrey and Wolff, 1977) and three 'dummy' flowmeters. The dummy flowmeters had the same diameter and turbine stator as the original flowmeter, but no rotor or electric connections. They therefore had the same resistance to air flow as the original flowmeter and by uncovering one or more of them, the range of the flowmeter could be increased from its original value of 0 - 80 l/min to 0 - 160, 0 - 270 or 0 - 360 l/min. The range used in a particular experiment depended on the expected maximum respiration rate. The flowmeter 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 diameter outlet valves into a flexible tube attached to the analysis and display unit fixed to the animals' 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 made corrections for atmospheric pressure, temperature and humidity and displayed the results as litres of oxygen consumed and air inspired corrected to standard temperature and pressure. In the present 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 an ergometer for work and distance, or odometer for distance only (Lawrence and Pearson, 1985).

The animals used in this experiment were already well trained for work. Further training was necessary to accustom them to carrying the instruments. Animals were trained for 3 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 energy cost of walking was measured on surfaces of different consistencies: unploughed wet sandy soils, ploughed wet sandy soils and firm laterite tracks.

During the first trial the work routine 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. During the walking 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 sequences 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 1000m circuit, pulling a cart loaded with 600 kg around the 1000m circuit and finally pulling a cart loaded with 900 kg around the 1000m circuit.

Heat production (H) was estimated using the equation: $H = 16.18\ O_2 + 5.02\ CO_2$ (Brouwer, 1965) where O_2 is the volume of oxygen consumed and CO_2 is the volume of carbon dioxide produced. Because methane and urinary nitrogen would have quantitatively little influence, they were omitted from the equation to calculate heat production proposed by McLean and Tobin (1987). Assuming a value of 0.9 for the respiratory quotient (the ratio of carbon dioxide produced : 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 = (energy used while walking - energy used while standing still) / (distance walked (m) × M (kg)). The energy cost of doing work was defined as an efficiency factor (E_f) according to Lawrence and Stibbards (1990) :E_f = (work done (kJ) / (energy expended when loaded (kJ) - 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 formulae (Lawrence and Stibbards, 1990) to predict the extra net energy required for ploughing sandy soils for 1 to 6 hours per day. The energy cost of ploughing was estimated assuming the average draught force (978 N for the team or 489 N for each animal) and the average walking speed (0.92 m/s) found in this study. This draught 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: $EM = 1.15(0.53(M/1.08)^{0.67}$, AFRC, 1993). The energy cost for maintenance was increased by proportionally 0.10 to account for the higher metabolic rate after work as compared to non-working days (Lawrence, Buck and Campbell, 1989) and for the higher underlying resting metabolic rate during work as compared to the resting metabolic rate during the same time of the day on non-working days (Lawrence, Sosa and Campbell, 1989).

Data analysis

E_w , E_f for each type of work and SMR were subjected to analysis of variance using the model:

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

Where:

Y = k^{th} observation of E_w , E_f or SMR, 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

Since repeated measurements were taken on animals over 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.

Results

Standing metabolic rate

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

Energy cost of walking

Ground surface affected E_w and walking speed ($P<0.01$). Average energy cost of walking by the oxen was 1.59 (s.e. 0.069), 2.15 (s.e. 0.084) and 1.00 (s.e. 0.10) J/m/kg M on unploughed, ploughed sandy soils and on laterite tracks, respectively (Table 1). 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 as compared with ploughed soils (Table 1). The regression of E_w on M was significant. The heavier the animal, the higher was the energy cost of walking. Each extra kg of M was associated with an increase of 0.013 J/m/kg 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 1).

Energy cost of working

The average draught force required to plough sandy soils in this experiment was 978 (s.e. 70) N. Ploughing was performed using a mouldboard plough at an average depth ranging from 12.9 (s.e. 0.68) to 17.1 (s.e. 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 of depth, respectively. Teams worked at an average speed of 0.92 (s.e. 0.044) m/s. The efficiency of ploughing was 0.32 (s.e. 0.056). Average draught forces during carting were 386 (s.e. 5.7), 486 (s.e. 6.5) and 574 (s.e. 6.4) N for the 300, 600 and 900-kg loads respectively. The type of activity, M, draught force and walking speed did not influence working efficiency (Table 2). The efficiency of doing work was only affected by individual animals, suggesting large variability between animals. The average efficiencies for oxen used in this experiment were: 0.31, 0.35, 0.30, 0.43 and 0.34 for ox no. 10, 13, 16, 21 and 24, respectively.

Quantification of the extra energy requirements for ploughing

Table 3 shows 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. Depending on M of the animal and the number of hours worked, the daily extra net energy expended for ploughing varied between 0.13 to 0.92 times the energy cost for maintenance.

Discussion

Standing metabolic rate (SMR)

The SMR in this study (5.63 s.e. 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 that 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.* (1989) 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 had a higher metabolic rate than the *Bos indicus* breeds used in this and the other experiments (Dijkman, 1993, Becker *et al.*, 1993). In Ethiopia, crossbred oxen were found to require more energy per unit of body weight for maintenance and work output than local oxen (Astatke, 1983). It is important to note first that the SMR reported in these studies is related to total M and not to empty body mass. Second, 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 by

Dijkman (1993) in Nigeria. As might be expected E_w on ploughed land was lower on the sandy soils in the present study (2.15J/m/kg M) than seen on ploughed land on the heavier soils with a higher clay content in valley-bottoms Nigeria, (3.76-8.58J/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 Ew 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 that was similar to the E_w measured on laterite tracks in this study. Field values recorded on the firm surfaces were usually lower than values determined on treadmills such as: 2.6 J/m/kg (AFRC, 1993), 1.9 J/m/kg (Brody, 1945) and 2.1 J/m/kg (Lawrence and Stibbards, 1990). Discrepancies between laboratory and field values of E_w can be explained by the artificial conditions of the former. 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 in 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, the energy cost of walking was no longer influenced by speed.

Energy cost of doing work

In this experiment the efficiency of doing work was not affected either by the type of work performed (ploughing versus carting with varying loads) or the draught force exerted. The efficiency of ploughing (0.32) was consistent with average efficiencies of pulling loads reported by Lawrence and Stibbards (1990). These results are also in agreement with Dijkman (1993) who found an average efficiency of 0.30 to 0.31 for oxen ploughing upland and valley bottom soils in Nigeria. Efficiency of doing work in the present study was unaffected by walking speed. This again agrees with the observations of Lawrence and Stibbards (1990).

In this experiment a mouldboard plough was used for the ploughing trial. Results showed that an average draught force of 978 N would be required to till at an average depth of 15 cm. The mouldboard plough can also be used for direct ridging on untilled sandy soils. Draught forces required to do both these tasks appear similar. For example the draught force required for ploughing (825 N) in semi-arid areas in Mali 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 draught forces comparable 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. It has been suggested that oxen can sustained work over a working day provided the draught force does not exceed about 11 kgf/100 kg M (Goe and McDowell,1980). This implies that a team totalling at least 890 kg is the ideal M for ploughing and ridging sandy soils in these semi-arid areas.

Lawrence (1985) estimated the energy expenditure of cattle working for 5.5h 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 hours/day. Over a shorter working day (3 h) Mahardika *et al.* (1994) estimated the extra energy expenditure of water buffaloes working at draught forces equivalent to proportionally 0.10 and 0.15 of M to be 0.42 and 0.48 times maintenance energy requirements, respectively. Using the values for E_w and the efficiency of doing work obtained in this study to estimate the extra net energy used for work according to the method of Lawrence and Stibbards (1990) gave values for the extra energy for work ranging from 0.13 to 0.92 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 hours of ploughing sandy soils varied between 0.54 for oxen weighing 500 kg to 0.92 x 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.* 1994), but energy expenditure during work by the 300 kg was higher than that generally found, suggesting that the larger animal (500 kg) is the better one to use for ploughing in the semi-arid areas.

The findings of this study can be used to accurately estimate the energy requirements for work in semi-arid areas through the application of the factorial method (Lawrence and Stibbards, 1990) provided work output (draught force (N) × 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 extensive livestock production systems prevailing in semi-arid areas. This information can be obtained through the monitoring of the daily activities of animals. This would allow the complete daily energy budget of draught animals be more exactly calculated for these areas.

Acknowledgements

Financial support from the Overseas Development Administration (ODA) of the United Kingdom and the International Livestock Research Institute is gratefully acknowledged. The authors also thank Salvador Fernández-Rivera for his constructive comments during preparation of the manuscript.

References

AFRC. 1993. *Energy and Protein Requirements of Ruminants.* An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

Astatke, A. 1983. *Feed and work trials at Debre Berhan, 1980-1982.* Working document, ILCA Highlands Programme, Addis Ababa.

Becker, K., Rometsch, M., Susenbeth, A., Roser, U. and Lawrence, P. 1993. Characterisation of the physiological performance and determination of the efficiency of draught oxen. Special Research Program (SFB 308). Intermediate Report 1991-1993. University of Hohenheim, Stuttgart, Germany.

Brody, S. 1945. *Bioenergetics and Growth.* Hafner Press, New York.

Brouwer, E. 1965. Report of the sub-committee on constants and factors. In: *Proceedings of the Third Symposium on the Energy Metabolism of Farm Animals* (ed: K.L. Blaxter), pp. 441-443, EEAP Publication **No. 11.** Academic Press, London.

Clar, U. 1991. *Entwichlung einer Feldmethode zur Messung des Energie Umsatzes bei Zugtieren.* PhD Thesis, University of Hohenheim.

Dijkman, J.T. 1993. *The measurement of draught ruminant energy expenditure in the field.* Ph.D. Thesis, University of Edinburgh.

FAO. 1987. *African Agriculture: the next 25 years.* The Food and Agriculture Organisation of the United Nations, Rome, Italy.

Goe, M.R. and McDowell, R.E. 1980. Animal Traction: Guidelines for utilisation. Cornell International Agricultural Development Mimeograph (USA) No.81 Ilhaca, NY Cornell University 84p.

Humpfrey, S.J.E and Wolff, H.S. 1977. 'The Oxylog'. Journal of Physiology (London) **267**: 12.

Khibe, T. and Bartholomew, P.W. 1993. Recherches aux possibilités de conditionnement des boeufs de labour à base de paille de brousse enrichie à l'urée et évaluation de son impact sur leur capacité de travail. In: *Research for Development of Animal Traction in West Africa.* (ed P.R. Lawrence, K. Lawrence, J.T. Dijkman and P.H. Starkey), pp. 175-179. Proceedings of the Fourth Workshop of the West Africa Animal Traction Network , Kano, Nigeria, 9-13 July 1990. West Africa Animal Traction Network, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Lawrence, P.R. 1985. A review of the nutrient requirements of draught oxen. In: *Draught Animal Power for Production* (ed J.W. Copland),. pp. 59-63. Proceedings of an International Workshop, James Cook University, Townsville, Qld, Australia, 10-16 July 1985. ACIAR Proceedings Series No. 10, ACIAR, Canberra.

Lawrence, P.R. and Becker, K. 1994. The effects of draft power on feed utilisation and reproduction in cattle and buffaloes. In: *Sustainable Small-scale Ruminant Production in Semi-arid and Sub-humid Tropical Areas* (ed K. Becker, P.R. Lawrenc, and E.R. Ørskov). pp. 101-121. Proceedings of an International workshop on September 24 1994 at the Institute for Animal Production in the Tropics and Sub-Tropics, University of Hohenheim, Stuttgart, Germany

Lawrence, P.R., Buck, S.F. and Campbell, I. 1989. The metabolic rate of oxen after work. *Proceedings of the Nutrition Society* **48:** 153A.

Lawrence, P.R. and Pearson, R.A 1985. Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science, (Cambridge* **105:** 703-714.

Lawrence, P.R., Sosa, R. and Campbell, I. 1989. The underlying 'resting' energy consumption of oxen during work. *Proceedings of the Nutrition Society* **48:** 154A.

Lawrence, P.R., Pearson, R.A. and Dijkman, J.T. 1991. Techniques for measuring whole body energy expenditure of working animals: A critical review. In: *Isotope and Related Techniques in Animal Production and Health.* pp. 211-232. Proceedings of an International Symposium on Nuclear and Related Techniques in Animal Production and Health, International Atomic Energy Agency and the Food and Agricultural Organisation of the United Nations, Vienna, 15-19 April 1991. International Atomic Energy Agency, Vienna.

Lawrence, P.R. and Stibbards, R.J. 1990. The energy cost of walking, carrying and pulling loads on flat surfaces by Brahman cattle and Swamp Buffalo. *Animal Production* **50:** 20-29.

Mahardika, I.G., Sastradipradja, D., Sumadi, I.K., Sutardi, T. and Kartiaso 1994. Energy expenditure of water buffaloes for draft power in the humid tropics. In: *Sustainable Small-Scale Ruminant Production in Semi-Arid and Sub-Humid Tropical Areas.* (ed K. Becker, P.R. Lawrence and E.R. Ørskov). pp. 127-130. Proceedings of an International workshop on September 24 1994 at the Institute for Animal Production in the Tropics and Sub-Tropics, University of Hohenheim, Stuttgart, Germany.

McLean, J.A. and Tobin, G. 1987. *Animal and Human Calorimetry.* Cambridge University Press. New York. 338 p.

Pearson, R.A. 1989. A comparison of draught cattle (*Bos indicus*) and buffaloes (*Bubalus bubalis*) carting loads in hot conditions. *Animal Production* **49:** 355-363

Panin, A. and Ellis-Jones, J. 1994. Increasing the profitability of draught animal power. In: *Improving Animal Traction Technology* (ed P.H. Starkey, E. Mwenya, and J. Stares) pp. 94-103. Proceedings of the First Workshop of the Animal Traction Network for Eastern and Southern Africa (ATNESA), 18-23 January 1992, Lusaka, Zambia. Technical Centre for Agricultural Co-operation (CTA), Wageningen, The Netherlands. CTA.

Starkey, P.H. 1994. A wide view of animal traction highlighting some key issues in eastern and southern Africa. In: *Improving Animal Traction Technology.* (ed P.H. Starkey, E. Mwenya and J. Stares). pp. 66-81. Proceedings of the First Workshop of the Animal Traction Network for Eastern and Southern Africa (ATNESA), 18-23 January 1992, Lusaka, Zambia. Technical Centre for Agricultural Co-operation (CTA), Wageningen, The Netherlands. CTA.

Stevens, A.P. 1994. Improving animal-powered tillage systems and weeding technology. In: *Improving Animal Traction Technology* (ed P.H. Starkey, E. Mwenya and J. Stares). pp. 168-181. Proceedings of the First workshop of the Animal Traction Network for Eastern and Southern Africa (ATNESA), 18-23 January 1992, Lusaka, Zambia. Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. CTA.

Zerbini, E., Gemeda, T., O'Neill, D.H., Howell, P.J. and Schroter, R.C. 1992. Relationships between cardio-respiratory parameters and draught work output in F1 crossbred dairy cows under field conditions. *Animal Production* **55:** 1-10.

Table 1. Energy costs of walking (E_w) and walking speed of oxen walking on ploughed soils, on unploughed soils and on laterite tracks.

Ground surface	No. of animals	No. of observation	E_w (J/m/kg)		Walking speed (m/s)	
			mean	s.e.	mean	s.e.
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 having different superscripts are significantly different. * $P< 0.05$; ** $P<0.01$.

Table 2. Draught force, walking speed and efficiency of ploughing and of carting (work done /energy used for work) by oxen working in pairs.

Activity	No. of animals	n	Efficiency of working		Draught force (N)		Walking speed (m/s)	
					mean	s.e.	mean	s.e.
Ploughing	5	19	0.32	0.056			0.92	0.044
Carting: Load (kg)								
300	5	18	0.37	0.029	362	37	1.25	0.020
600	5	17	0.35	0.036	478	45	1.25	0.020
900	5	16	0.34	0.026	548	32	1.22	0.021

Table 3. Live weight, draught 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 the ploughed soil (A) and the other walking on the 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	0.13	0.15	0.26	0.31	0.39	0.46	0.52	0.62	0.65	0.77	0.78	0.92
400	0.12	43.12	0.12	0.15	0.25	0.30	0.37	0.45	0.49	0.61	0.52	0.76	0.75	0.91
500	0.10	50.99	0.11	0.13	0.21	0.26	0.32	0.39	0.43	0.52	0.44	0.65	0.64	0.78

[1]Nutrition of draught animals in semi-arid West Africa. II. Effect of work on intake, digestibility and rate of passage of food through the gastro-intestinal tract in draught oxen fed on crop residues.

A. Fall[1], R.A. Pearson[1], P.R. Lawrence[2+] and S. Fernández-Rivera[2]

[1]*Centre for Tropical Veterinary Medicine, University of Edinburgh, Midlothian EH25 9RG, Scotland, UK*
[2]*International Livestock Research Institute, ICRISAT Sahelian Centre BP 12404, Niamey, Niger*

Abstract

Two experiments were conducted to investigate the relationships between work and intake and digestion of food by draught oxen fed on millet stover. In the first experiment intake of millet stover, water intake, live weight, plasma concentrations of T_3, T_4 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 6 animals working either 0, 2.5 or 5 hours/day. Work did not affect intake of millet stover, 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 fed. 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 mobilised 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.

Key words: work, intake, digestibility, draught oxen, millet stover

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 feeds available before and during the early part of the cropping season in semi-arid areas often limit nutrient intake by oxen. Food intake can be influenced positively or negatively by work through direct or indirect mechanisms. Direct effects of work on food intake occur through

---

[+] Present address: Centre for Agriculture in the Tropics and Subtropics. Institute of Animal Production, Department of Animal Nutrition and Aquaculture. Universität Hohenheim (480), D-7093, Stuttgart, Germany physiological changes resulting from exercise. Muscular activity induces a higher metabolic rate in working animals as compared to 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 Beed, 1985).

The 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 ruminants (Pearson and Lawrence, 1992). Time of feeding also affects food intake. Bakrie and Teleni (1991) reported reduced food 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 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 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 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. The objective of this study was to investigated the relationships between food intake and the efficiency of utilisation of feeds 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), ICRISAT Sahelian Centre, Sadore, Niger. Eighteen local zebu oxen, aged 4-8 years, average live weight 302 (s.e. 18) kg, were used. All animals were dewormed and vaccinated against rinderpest, anthrax, and pasteurellosis. Oxen were housed in individual concrete floored 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 food and food spillages.

Oxen were trained to pull common farm implements and 55-kg metal sledges. They were fed chopped millet stover *ad libitum* except over 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 1). The concentrate was fed when animals returned from work in the morning at about 11:00 hours. Millet stover was given when oxen finished eating the concentrate, and at 16:00 and 18:00 hours. Food troughs and buckets were withdrawn from all the pens when oxen on exercise schedule were working. Therefore all animals had equal time of access to food, but assuming work restricted rumination, they did not have similar time available to ruminate. Orts were regularly removed from troughs so that animals could have access to finer components of the food. Oxen at rest were tethered out of the pens under the sun when other teams were working.

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 of average weight of 245, 273, and 390 kg for group 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 were divided into three 3-week periods. Treatments were applied in sequence to teams during experimental periods. During each period 3 teams were idle, 3 teams were working 2 h/day and 3 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 feeds: 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 polarisation immunoassay technique with an Abbot TDx Analyser (Abbot laboratories, USA). The analysis of 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 food 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 (food 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: 2h/day and l=3:4h/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 (W_m) live weight changes were estimated by regression analysis and were further subjected to analysis of variance using generalised linear models (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 4-7 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. 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 DM/kg $M^{0.75}$ at 12:00 hours 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 5h/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 0.10 of the team live weight. Work was performed continuously, 7 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 crossover design was used. Twelve oxen were assigned to the three treatment groups, 2 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 4 oxen were idle, 4 oxen were working 2.5h/day and 4 oxen were working 5 h/day.

Measurements

Work: During the preparation phase of this experiment, an ergometer was used 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 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 food: The millet stover used in this experiment was bought from different villages and different periods after grain harvest. Variation in proportion of leaf in the stover was then expected. A sampling procedure was set up to determine the proportion of leaf in the millet stover each week. Each day a sample of millet stover was taken before chopping. 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. Sampling of food and refusals for subsequent laboratory analysis were as Experiment 1.

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 (0.05) was taken and frozen. At the end of each 7-day collection period, daily samples were thawed, mixed and a sub-sample (1kg) 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, Baber and Archibald, 1989). On that day food was withdrawn at 14:00 until 23:00 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 185h 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, 2 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-hour 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-hour composite behaviour pattern of the animals. This scheme was applied 3 consecutive times. During each 5-min observation period each of the 6 animals was observed. The time spent doing a particular activity (eating, ruminating, standing, lying) was estimated as the product between the number of times this activity was observed and the interval between observations (5 min).

Body weight and condition: Oxen were weighed daily three times in a row during the three first days in each week. Body condition was assessed at the start and at the end of each 2-week period (Nicholson and Butterworth, 1986). Blood samples were collected as described in Experiment 1.

Laboratory analysis

Food, refusals and faeces samples, and plasma T_3, T_4 and PUN were analysed as described in Experiment 1.

Statistical analysis

Data were analysed using SAS GLM procedures (SAS, 1985). The following statistical models were used.

1. Daily intake of millet stover (g/kg M, g/kg $M^{0.75}$)

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

2. Digestibility coefficients

$$Y_{ijkl} = \mu + S_i + O(S)_{(i)j} + P(S)_{(i)k} + A_l + E_{ijkl}$$

where:

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

S_i : effect of i^{th} square, i=1,..4

$O(s)_{(i)j}$: effect of the j^{th} oxen nested within i^{th} square, j=1,..4

$P(S)_{(i)k}$: 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: 2.5h/day

and l=3:5h/day
W_m : effect of the mth week, m=1,2
$W*P_{mk}$: interaction between the mth week and the kth period
$W*A_{ml}$: interaction between the mth week and the lth work level
$(W*S)_m$ effect of the mth week and the ith square
W*O (s) interaction between the mth week and the jth oxen 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.

Orthogonal linear and quadratic polynomials were used to test the effect of treatment (i.e. A_l). A regression analysis of 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 40.0, 93.0 and 67.4% during the morning working sessions and 44.0, 96.0 and 60.0% during the afternoon working sessions.
Plasma T_4 and T_3 concentrations were not affected by level of work (Table 2). Plasma T_4 concentrations were 56.3 (s.e. 1.2), 52.7 (s.e. 1.2) and 52.3 (s.e. 1.2) nmol/l for oxen working 0, 2 and 4h/d. Plasma T_3 concentrations were 0.95 (s.e. 0.03), 0.94 (s.e. 0.03) and 0.98 (s.e. 0.03) nmol/l for oxen working 0, 2 and 4 h/day. There was a significant reduction ($P<0.05$) of T_4 and T_3 concentrations over time. The quadratic effect of week on T_3 concentration was also significant ($P<0.01$). T_3 concentration was lower during the second than during the first and the third week.

There was a significant linear ($P<0.01$) increase in PUN as level of work increased. PUN was 4.00 (±0.14), 4.53 (±0.14) and 4.83 (±0.14) mml/l for oxen working 0, 2 and 4 h/day. PUN concentrations were significantly higher during week 2 than during weeks 1 and 3.

Mean daily work output was 3233 (CV=22%) and 6763 (CV=33%) kJ for ox teams working 2 and 4 h/day, respectively. Average draught force and power developed were 0.89 (CV=26%) N/kg M, 583 (CV=11%) W and 90 (CV=28%) W/100kg M, respectively, for ox teams working 2 h/day. Average draught force and power for oxen working 4h/day were 0.88 (CV=23%) N/kg M, 616 (CV=10%) W and 92 (CV=19%) W/100kg M, respectively (Table 3).

Daily dry matter intake (DMI) of millet stover was not affected by number of hours worked per day. There was a significant linear increase over 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 ($P<0.05$). Daily food intake of oxen at-rest were 15.5 (s.e. 0.18), 15.48 (s.e. 0.18) and 15.9 (s.e. 0.18) g DM/day/kg M in week 1, 2 and 3, respectively. 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 3 shows daily work characteristics, food and water intake and weekly live weight changes. Food intakes of animals working 2 and 4h/day include food consumption on non-working and working days. High intensities of work (4h/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 (Figure 1).

There were no significant differences due to work in water consumption expressed in l/day, l/kg M, l/kg $M^{0.75}$ or l/kg DMI (Table 3). Oxen working 0, 2 and 4 h/day consumed 30.5 (s.e. 0.5), 30.2 (s.e. 0.5) and 30.3 (s.e. 0.5) l/day, respectively. Volume of water consumed per kg of DM eaten was 6.45 (s.e. 0.097), 6.32 (s.e. 0.097) and 6.58 (s.e. 0.097) litres per day for oxen working 0, 2 and 4 h/d. In this experiment, oxen at-rest were tethered in the sun while other teams were working.

Body weight change was significantly affected by work ($P<0.05$). Weekly weight gains were 3.72 (s.e. 0.76), 1.58 (s.e. 0.84) and -2.19 (s.e. 0.82) kg for oxen working 0, 2, 4 h/day, respectively (Table 3).

Experiment 2

There was a significant linear ($P<0.05$) increase in PUN concentration as work level increased. PUN concentrations were 3.51 (s.e 0.18), 3.81(s.e. 0.18) and 4.66 (s.e. 0.18) mmol/l for animals working 0, 2.5 and 5 h/day. 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 (Figure 2). There was a change of -0.06 (s.e. 0.021), 0.043 (s.e. 0.021) and 0.094 (s.e. 0.021) mmol/l per week for animals working 0, 2.5 and 5 h/day, respectively.

Plasma T_4 concentration was affected by week ($P<0.001$) and the interaction between work and week ($P<0.05$). T_4 concentration decreased as work level increased (Table 4). This decrease at the highest work load. The rate of change of T_4 was -0.16 (s.e. 0.18), -0.54 (s.e. 0.18) and -1.02 (s.e. 0.18) nmol/l per week for animals that worked 0, 2.5 and 5 h/day, respectively. There was a significant linear decrease ($P<0.01$) in plasma T_3 concentrations as work load increased and over weeks ($P<0.001$). T_3 concentration was 0.68 (s.e. 0.23), 0.61 (s.e. 0.23) and 0.55 (s.e. 0.23) nmol/l for animals working 0, 2.5 and 5 h/day, respectively.

Intake of millet stover was not significantly influenced by work. Table 4 shows mean DMI, water intake and live weight over 2-week experimental periods for oxen working 0, 2.5 and 5 h/day. Animals working 0, 2.5 and 5h/day consumed daily 15.1, 16.2 and 16.2 g DM/kg M, respectively. 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:

DMI (g/kg M) = $12.8(\pm1.09) + 5.4(1.18) \times \text{PLS}$ $P<0.01$ $R^2 = 0.30$

DMI (g/kg $M^{0.75}$) = $52.5(\pm4.44) + 20.8(7.65) \times \text{PLS}$ $P<0.01$ $R^2 = 0.28$

There was a significant increase in water intake as work level increased. Water consumption was 7.9, 9.3 and 10.8 l/100 kg M for oxen working 0, 2.5 and 5 h/day.

Work caused live weight losses whereas oxen at-rest were able to maintain their body weight. Live weight of ox teams declined from 610 kg during the first week of work to 602 kg for animals that worked 2.5 h/day and from 615 to 597 kg for animals that worked 5 h/day.

There was no significant effect of work on the digestibility of DM, OM, ADF, NDF, hemicellulose (HEM) and GE. Table 5 shows coefficients of digestibility for different work loads. Increases in the proportion of leaves in the food offered improved digestibility coefficients as illustrated by the regression of digestibility coefficients on PLS given in the following equations:

$$\text{DMD} = 0.03\ (\pm 0.08) + 0.69\ (\pm 0.08) \times \text{PLS} \quad P<0.01,\ R^2 = 0.68$$
$$\text{ADFD} = 0.25\ (\pm 0.04) + 0.52\ (\pm 0.08) \times \text{PLS} \quad P<0.01,\ R^2 = 0.52$$
$$\text{NDFD} = 0.19\ (\pm 0.04) + 0.68\ (\pm 0.08) \times \text{PLS} \quad P<0.01,\ R^2 = 0.69$$
$$\text{OMD} = 0.06\ (\pm 0.05) + 0.70\ (\pm 0.09) \times \text{PLS} \quad P<0.01,\ R^2 = 0.65$$
$$\text{HEMD} = 0.14\ (\pm 0.05) + 0.87\ (\pm 0.09) \times \text{PLS} \quad P<0.01,\ R^2 = 0.72$$
$$\text{GED} = 0.12\ (\pm 0.04) + 0.67\ (\pm 0.08) \times \text{PLS} \quad P<0.01,\ R^2 = 0.66$$

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 15 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 ($P<0.05$). The MRT for animals working 2.5 h/day (78.2 s.e. 2.3 h) was lower than MRT for animals working 5 h/day (82.2 s.e. 2.3 h) or for animals at-rest (88.9 s.e. 2.3 h).

Work did not significantly affect time spent eating and ruminating or eating and rumination rates (Table 5).

Discussion

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 due to the extra heat load from increased muscle metabolism in the working animal. The absence of significant difference in plasma T_3 and T_4 concentrations between working oxen and oxen at-rest in Experiment 1 may be because oxen at-rest were sufficiently heat stressed by radiant heat gains. They were exposed to solar radiation and ambient temperatures were high. Alternatively, the work load may not have caused a level of heat stress that could induce significant changes in plasma thyroid hormone concentrations in the working animals.

In Experiment 2 plasma concentrations of T_3 and T_4 decreased steadily over time and the higher the work load the greater the decrease in 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.

In both experiments there was a linear increase in PUN as the work level increased. This suggested that during weight loss in working periods oxen were catabolizing amino acids to supply energy-yielding substrates for work.

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 working animals 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 accounted for the working oxen consuming significantly more water than non-working oxen in this experiment.

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 this study DMI was depressed during the first week for oxen working 4 h/day. These animals, however, increased DMI the following weeks. By the third week they were eating as much as oxen at rest or working 2 h/day. This suggests that when oxen are subjected to a high work load (more than 4 h/day), food intake is depressed during the first days of work and improves progressively the following days as oxen adapt to work. 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. Similarly, during Experiment 2, work did not have a significant effect on intake of millet stover.

Significant depression of food intake on working days is reported by Pearson (1990) and Pieterson and Teleni (1991). In contrast, Bakrie *et al.* (1989) found significant increases in food intake on working days. 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 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.* (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). These authors found that food intake was reduced when access to food was restricted for 7 hours/day and was further reduced when animals worked for 5 hours during these 7 hours of food restriction. 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 was not 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 5h 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 feed restriction for 4 h, with or without work on intake of straw diets by cattle and buffalo.

Pearson and Lawrence (1992) studied the nature of the diet on the response to work. They concluded that time available to eat and ruminate could be a constraint to food intake when oxen were fed on a poorly digestible, fibrous diet as compared with more digestible diets. In Experiment 2 food intake was significantly affected by the proportion of leaves in the stover and therefore by the quality of the diet. Powell (1985) suggested that the higher consumption of leaves of millet stover by cattle grazing crop residues could be attributed to cattle being more selective of fine plant parts which had a higher protein content than stems and were more digestible. 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.

Plant characteristics are an important determinant of food intake in ruminants. 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 to 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.

Faverdin, Baumont and Ingvartsen (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. These authors based this assumption on the pattern of change of food intake in lactating cows. 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 importance 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 for 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. Draught animals work intensively for about 9 weeks during the cropping season in semi-arid areas. It is therefore worthwhile investigating the long term pattern of change in food intake by draught oxen fed on roughages.

In this study, apparent DM digestibility and the digestibility of food fractions were not significantly affected by work. These results agree with those reported by several others (see Pearson and Dijkman, 1994). Significant increases in digestibility, as a result of work, were reported by Soller, Reed and Butterworth (1991) and Zerbini *et al.*(1995) in Ethiopia, and Pearson and Lawrence (1992) in Nepal. In the present study, a significant improvement in food 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 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 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 feeds in the digestive tract. The hypothesis that work is associated with a delay in transit time of food in the digestive tract (Pearson and Lawrence, 1992) is not supported by results from this study.

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/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/kg $M^{0.75}$) but animal had opportunities to select more leaves from the millet stover given as excess (0.50) millet stover was offered. During Experiment 1, energy requirements for work could be met by intake when animals worked 2 h/day, insuring 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 energy requirements could not be met from intake alone.

Conclusions

Although the rate of passage of undigested food residues tended to increase with light work, oxen fed on 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 mobilised their body reserves to supply energy to working muscles. Hence weight losses is a constant feature in working oxen relying on roughages. During this study, oxen working more than 2 h/day lost live weight and PUN increased as work level increased suggesting that oxen were catabolizing amino acids. Oxen could maintain their weight during resting periods when they were fed 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 feeds, it may be relevant to predict food 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 food 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.

Acknowledgements

The authors thank the Overseas Development Adiministration (ODA) of the United Kingdom and the International Livestock Research Institute for funding this study.

References

Association of Official Analytical Chemists 1990. *Official Methods of Analysis of the Association of Analytical Chemists.* 15th ed. Association of Analytical Chemists, Virginia, USA.

Bakrie, B., Murray, R.M., Hogan, J.P., Teleni, E. and Kartiarso 1989. Effect of load level on feed utilisation by working cattle and buffaloes. *DAP Project Bulletin* **8:** 23-26.

Bakrie, B. and Teleni, E. 1991. The effect of time of feeding in relation to work on draught animals. I. The effect of feeding high fibre diet either before or after work on feed utilisation and physiology of working buffaloes. *Draught Animal Bulletin* **1:** 39-45.

Bakrie, M., Murray, R.M. and Hogan, J.P. 1988. The effect of work on intake and ruminal fluid, volatile fatty acid and NH_3 concentration of steers fed Rhodes grass hay. *DAP Project Bulletin* **8:** 23-26.

Bamualim, A., Ffoulkes, D. and Fletcher, I.C. 1988. Effect of work and level of feeding intake on nutritional parameters and bodyweight change of swamp buffalo cows. DAP Project Bulletin, 7: 2-7.

Christopherson, R.J. and Kennedy, P.M. 1983. Effect of the thermal environment on digestion in ruminants. *Canadian Journal of Animal Science* **63:** 477-496.

Collier, R.J. and Beede, D.K. 1985. Thermal stress as a factor associated with nutrient requirements and interrelationships. In *Nutrition of Grazing Ruminants in warm climates* (ed L.R. McDowell), pp. 59-71. Academic Press, London.

El-Nouty, F.D. and Hassan, G.A. 1983. Thyroid hormone status and water metabolism in Hereford cows exposed to high ambient temperature and water deprivation. *Indian Journal of Animal Science* **53:** 807-812.

Faverdin, P., Baumont, R. and Ingvartsen, K.L. 1995. Control and prediction of feed intake in ruminants. In *Recent Developments in the Nutrition of Herbivores.* (ed M. Journet, E. Grenet, M-H. Farce, M. Theriez and C. Demarquilly), pp. 95-120. Proceedings of the Ivth International Symposium on the Nutrition of Herbivores. INRA Editions, Paris.

Forbes, J.M. 1995. *Voluntary Food Intake and Diet selection in Farm Animals.* CAB International, Wallingford, UK, 532p.

Ffoulkes, D. 1986. Studies on working Buffalo- current research on nutritional aspects. *Draught Animal News* **6:** 7-13.

Grovum, W.L. and Williams, V.J. 1973. Rate of passage of digesta in sheep. 4. Passage of marker through the alimentary tract and the biological relevance of rate-constants derived from the changes in concentration of marker in faeces. *British Journal of Nutrition* **30:** 313-329.

Johnson, H.D. 1982. Role of physiology in cattle production in the tropics. In: *Animal Production in the Tropics* (ed. M.K. Yousef), pp. 3-28. Preager Publisher.

Johnson, H.D. 1987. Bioclimate effects on growth, reproduction and milk production. In *Bioclimatology and the Adaptation of Livestock* (ed. H.D. Johnson), pp. 35-57. Elsevier, Amsterdam.

Lawrence, P.R. and Pearson, R.A 1985. Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science, Cambridge* **105:** 703-714.

Mathers, J.C., Baber, R.P. and Archibald, R.F. 1989. Intake, digestion and gastro-intestinal mean retention time in Asiatic buffaloes and Ayrshire cattle given two contrasting diets and housed at 20and 33 *°C. Journal of Agricultural Science Cambridge* **113:** 211-222.

Matthewman, R.W. and Dijkman, J.T. 1993. The nutrition of ruminant draught animals. *Journal of Agricultural Science, Cambridge* **121:** 297-306.

Nicholson, M.J. and Butterworth, M. 1986. *A Guide to Condition Scoring of Zebu Cattle.* International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia. 36 p.

Pearson, R.A. 1990. A note on live weight and intake and digestibility of food by draught cattle after supplementation of rice straw with the fodder tree *Ficus auriculata. Animal Production* **51:** 635-638.

Pearson, R.A. and Archibald, R.F. 1990. Effect of ambient temperature and urea supplementation in the intake and digestion of alkali-treated straw by Brahman cattle and Swamp buffaloes. *Journal of Agricultural Science, Cambridge* **114:** 177-186.

Pearson R.A. and Dijkman, J.T. 1994. Nutritional Implications of work in draught animals. Proceedings of the Nutrition Society, 53: 169-179.

Pearson, R.A. and Lawrence, P.R. 1992. Intake, digestion, gastro-intestinal transit time and nitrogen balance in working oxen: studies in Costa Rica and Nepal. *Animal Production* 55: 361-370.

Pearson, R.A. and Smith, D.G. 1994. The effects of work on food intake and digestive behaviour of draught cattle and buffalo given barley straw. *Animal Production* **58:** 339-346.

Pieterson, R. and Teleni, E. 1991. The effect of work on nitrogen economy of female swamp buffaloes. *Draught Animal Bulletin* **1:** 30-31.

Powell, J.M. 1985. Yields of sorghum and millet and stover consumption by livestock in the subhumid zone of Nigeria. *Tropical Agriculture, Trinidad* **62:** 77-81.

Preston, T.R. and Leng, R.A. 1987. *Matching ruminant production systems with available resources in the tropics and sub-tropics.* Penambul Books, Armidale, Australia. 245 p.

Soller, H., Reed, J.D., Butterworth, M.H. 1991. Effect of work on utilisation of cereal crop residues by oxen. *Animal Feed Science and Technology* **33:** 297-311.

Statistical Analysis System Institute (SAS). 1985. SAS User's Guide. Statistics. SAS Institute Inc., Cary, NC, USA.

Weston, R.H. 1985. Some considerations of voluntary feed consumption and digestion in relation to work. In *Draught animal power for production* (ed.J.W. Copland), pp. 78-83. Proceedings of an international workshop, James Cook University, Townsville, Qld, Australia, 10-16 July 1985. ACIAR Proceeding Series **No 10.** ACIAR, Canberra

Youssef, M.K. 1987. Principles of Bioclimatology and adaptation. In *Bioclimatology and the Adaptation of Livestock* (ed. H.D. Johnson), pp. 17- 31. Elsevier, Amsterdam.

Zerbini, E., Gemeda, T., Wold, A.G., Nokoe, S. And Demissie, D. 1995. Effect of draught work on performance and metabolism of crossbred cows. 2. Effect of work on roughage intake, digestion, digesta kinetics and plasma metabolites. *Animal Science* **60:** 369-378.

Table 1. **Chemical composition of millet stover and concentrate feed given during Experiments 1 and 2. Except for dry matter (DM) and gross energy (GE), values are expressed as g/kg DM.**

Feed component	Millet stover		Concentrate	
	Expt 1	Expt 2	Expt 1	Exp 2
Dry matter (%)	90.2	94.0	90.5	93.5
Crude protein	33	36	293	177
GE(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

Table 2. **Plasma concentrations of thyroxine (T_4), triiodothyronine (T_3) and urea-N (PUN) in oxen working 0, 2, and 4 h/day (Experiment 1).**

	T_4 nmol/l	T_3 nmol/l.	PUN mmol/l
Work level			
0h/d	56.3	0.95	4.00
2h/d	52.7	0.94	4.53
4h/d	52.3	0.98	4.83
s.e.	1.2	0.03	0.14
signif.:	NS	NS	Linear**
Week			
1	57.9	1.05	4.33
2	52.64	0.84	4.77
3	50.79	0.98	4.27
s.e.	1.15	0.03	0.14
signif.:	linear*	linear* Quad**	Quad**

NS, not significant, * : P<0.05, ** :P<0.01

Table 3. **Daily work output, load, and power and intake of millet stover, water intake and live weight change for oxen working 0, 2 and 4 h per day (Experiment 1).**

Variables	Work 0 h/day		Work 2 h /day		Work 4 h/day		Significance
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	s.e.	Mean	s.e.	Mean	s.e.	
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							
litre (l)	30.5	0.47	30.2	0.51	30.3	0.51	NS
l/kg M	0.099	0.001	0.099	0.002	0.101	0.002	NS
l/kg $M^{0.75}$	0.41	0.007	0.42	0.008	0.42	0.008	NS
l/kg DMI	6.45	0.09	6.32	0.09	6.58	0.09	NS
Live weight change							
kg/week	3.72	0.76	1.58	0.84	-2.19	0.82	

Values in parenthesis are CVs, NS not significant

Table 4. **Least square means of intake of millet stover, water intake, live weight and plasma concentration of urea-N (PUN) of oxen working 0, 2.5 and 5 hours/day (Experiment 2)**

Work level	Work 0h/day	Work 2.5h/day	Work 5h/day	s.e.
Intake of millet stover				
g/kgM	15.13	16.22	16.15	0.20 NS
g/kgM$^{0.75}$	61.36	65.82	65.51	0.83 NS
Water intake				
l/day	21.35^{a}	25.200^{b}	28.510^{c}	0.380
l/kgM	0.079^{a}	0.093^{b}	0.108^{c}	0.014
l/kgM$^{0.75}$	0.320^{a}	0.380^{b}	0.430^{c}	0.050
l/kgDMI	5.370^{a}	5.830^{b}	6.440^{c}	0.120
PUN (mmol/l)[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,

[abc]: Values in the same row with different supercripts are significantly different:

Table 5. **Effect of work on food apparent digestibility, gastrointestinal rate of passage of solid particles, thyroxine (T_4) and triiodothyronine (T_3) plasma concentrations, and feeding behaviour parameters in oxen (Experiment 2)**

Work level	Work 0h/day	Work 2.5h/day	Work 5h/day	s.e.	Significance
Digestibility (%)					
DM	0.42	0.43	0.43	0.011	NS
OM	0.45	0.46	0.45	0.012	NS
ADF	0.54	0.54	0.55	0.010	NS
NDF	0.57	0.57	0.58	0.009	NS
HEM	0.63	0.63	0.65	0.009	NS
ENERGY	0.49	0.49	0.51	0.009	NS
T_4 (nmol/l) [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	
T_3 (nmo/l) [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
MRT (h)	88.9	78.2	82.2	2.3	Quad. *
TT (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; * : $P<0.05$,

Figure 1. Intake of millet stover (g/kgLW$^{0.75}$ per day) over 3 weeks by oxen working 0, 2 and 4 h/day (Experiment 2)

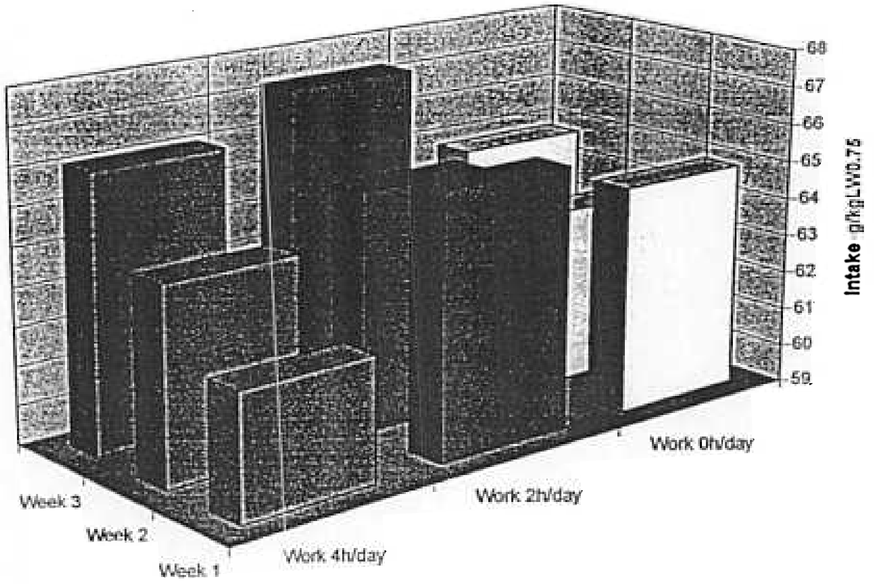
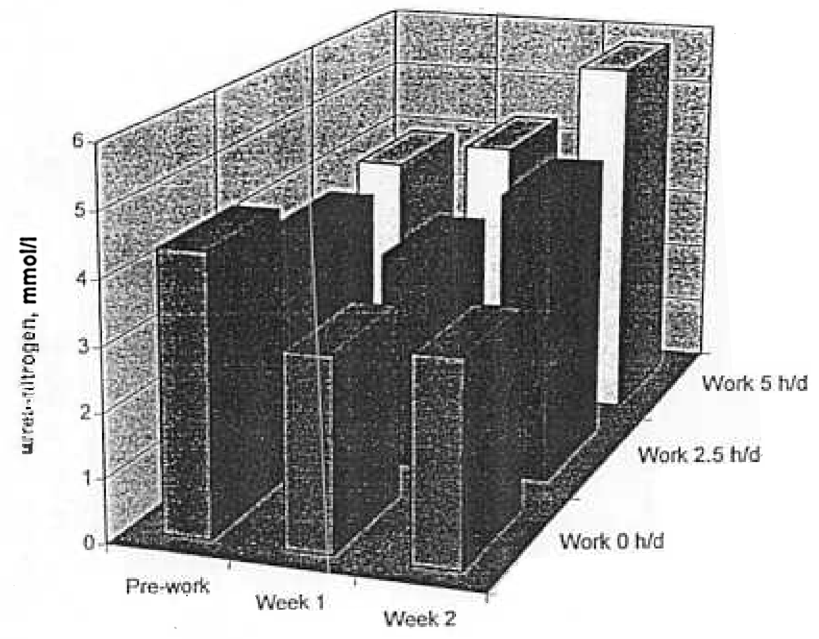


Figure 2. Plasma urea-N concentration of oxen before work and during 2 weeks when they worked for 0, 2.5 and 5 h/day



Nutrition of draught oxen in semi-arid West Africa. III. Effect of body condition prior to work and weight losses during work on food intake and work output.

A.Fall[1], R.A. Pearson[1] and S. Fernández-Rivera[2]

[1]*Centre for Tropical Veterinary Medicine, University of Edinburgh, Midlothian EH25 9RG, Scotland, UK.*
[2]*International Livestock Research Institute, ICRISAT Sahelian Centre, BP 12404, Niamey, Niger*

Abstract

Eighteen oxen were allotted to 3 treatment groups according to their body condition: poor, medium and good. Work output, speed, live weight and body condition were measured during 7 weeks when animals worked 4 days/week, 4 hours/ day, pulling loads equivalent to 12.5 kgf/100 kg live weight. The animals were fed millet stover ad libitum during hours they did not work plus 10 g/kg M of a concentrate mix. Work did not influence intake of millet stover. However, food intake improved as work progressed and animals in bad condition ate more millet stover than animals in good body condition. Work performance was affected by live weight, but not body condition. Live weight losses did not have a detrimental effect on work performance. Power output improved during the course of the experiment while animals were losing weight. Animals in all treatment groups lost body weight during the 7 weeks of work, but weight losses were more pronounced in oxen in good than in poor body condition. At the end of the working period, animals were fed natural pastures without supplementation. It took 4 weeks for animals in poor and medium body condition and 6 weeks for animals in good body condition to reach their pre-work live weight.

Key words: Work output, body condition, live weight, intake, millet stover

Introduction

Draught oxen in good condition and of suitable live weight are required to ensure timeliness in soil preparation and in planting, crucial for successful cropping in semi-arid areas of West Africa. This is because work output is a function of body size and working animals preferably use long chain fatty acids from fat reserves to fuel muscular activity during sustained exercise (Preston and Leng, 1987; Pethick, 1993). Unfortunately, draught 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 draught oxen for maintenance, let alone work. 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). Although the cropping season is short in semi-arid areas, many oxen are hired out or loaned to other farmers and used for transport. Hence those oxen that are available may be used over extended periods.

Supplementary feed is often recommended as a means to produce draught oxen in good condition and live weight to optimise power available. However, feed supplementation is expensive. Furthermore, investigations of the effect of dry season supplementation on draught oxen have generally failed to show any significant benefit of committing scarce feed resources to work output and consequently to better crop production (Astatke, Reed and Butterworth, 1986; Khibe and Batholomew, 1993; Dicko and Sangaré, 1984). Feeding strategies for draught 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 the relationship between body weight, body condition, weight loss during work and work output of draught oxen have been investigated.

Material and methods

Animals and feeding

This experiment was conducted from July to September 1994 at the ICRISAT Sahelian Centre in Niger. Eighteen oxen, age 4-7 years, average live weight 326 kg, were used. They were given chopped millet stover *ad libitum*, supplemented daily with 10g DM/kg $M^{0.75}$ of a concentrate mix made up (g/kg) of wheat bran (500), groundnut cake (350), rock phosphate (50), crushed bone (50) and common salt (50). 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 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). Three pairs of oxen were assigned to each of the three treatment groups with average body condition scores of 2.33, 3.67 and 5.67 for groups 1, 2 and 3, respectively. Average weight of teams in groups 1, 2 and 3 were 615, 650 and 692 kg, respectively.

The experiment lasted 7 weeks. Teams worked 4 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 or 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 draught force exerted was equivalent to 12.5 kgf/100 kg M. The following equation was used to determine work loads: Load (kg) = 0.201× 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 3 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 (Fall *et al.* 1996b).
At the end of the 7 weeks of work, 10 animals were monitored for two months to investigate the rate of weight gain after work. The animals grazed rainy season natural pastures from 08:30 to 17:00 hours without supplementation. They were kept in stables after grazing and had access to water *ad lbitum*. M was measured for a two month period every second day in the morning before grazing.

Data analysis

During the course of the experiment 2 oxen, 1 in team 3 ('poor' IBC) and 1 in team 6 ('medium' IBC), were impaired by joint disorders. They were consequently allowed to rest from the fifth week of the experiment. 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 study. The data set used to analyse daily intake of millet stover and daily weight changes included all weeks and all oxen except ox 17 and 25. Teams 3 and 6 were excluded from the analysis of speed, power and work output.

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

1 Intake of millet stover (g/d/kg M and g/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/100kg 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=0: rest, k=1: 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 others 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.

Results.

Linear effect of IBC ($P<0.05$) and the linear and quadratic effect of week ($P<0.05$) on daily intake of millet stover (g/d/ kg M; g/d/ kg $M^{0.75}$) were seen (Table 1). Oxen in 'poor', 'medium' and 'good' IBC consumed 75.1 (s.e.1.08), 72.9 (s.e.1.07) and 64.8 (s.e.0.93) g/d/ kg $M^{0.75}$, respectively. 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.

Differences ($P<0.01$) in daily weight gain due to IBC were seen. All oxen lost weight during the experiment, but weight losses were highest in oxen in 'good' IBC. Daily weight losses were 456 (s.e. 103.3), 308 (s.e. 103.3) and 719 (s.e 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 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 Figure 1. The pattern of live weight 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.

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

$M = 257(\pm 12) + 0.825(\pm 0.054) \times D$ for oxen in 'poor' IBC (at the start of the experiment),
$M = 302(\pm 12) + 0.967(\pm 0.041) \times D$ for oxen in 'medium' IBC (at the start of the experiment),
$M = 303(\pm 11) + 0.870(\pm 0.037) \times D$ 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 when M change was expressed relative to the initial M of oxen, 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 4 weeks, on average, after work stopped. It took 6 weeks after the cessation of work for oxen in 'good' IBC to reach their pre-work M.

IBC did not affect speed of work of teams. Power (W) developed by teams in 'poor' and 'medium' IBC was similar, but significantly lower than power output (W) of oxen in 'good' IBC (P<0.01). However, when power was expressed relative to live weight (W/100kg M), the effect of IBC was no longer significant. Three oxen teams with approximately similar M 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 of work were significant (P<0.01, Table 2). 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 effect (P<0.01) on speed and power output. Two contrasting phases were observed in the pattern of power output each day. During the first 3 laps of work (first hour), there was an increase of 0.01 m/s and 9 W in speed and power each lap. In the second phase starting from the fourth lap a steady decline in speed and work output of 0.014 m/s and 10.3 W were observed for each lap completed. Oxen in all body condition groups exhibited a negative energy balance. Calculation of energy balance from estimated energy intake and energy used for work according to Fall, Pearson and Lawrence (1996a) agreed with observed values (Table 3).

Discussion

As in previous studies (Fall *et al*, 1996a) work did not affect intake of millet stover. These results are consistent with most other studies that indicated no differences in intake in working animals as compared with animals at-rest (reviewed by Pearson and Dijkman, 1994). Poor body condition before work was conducive to higher intake of millet stover than good body condition before work over 7 weeks. Increases in dry matter intake were seen in cows with a low body condition as compared to those in a better body condition, in early lactation by (Jones and Garamsworthy, 1989). As suggested by Faverdin, Baumont and Ingvartsen (1995), undernutrition induces an increase in food intake when food unavilability is no longer a limiting factor.

The steady increase in food intake and power output over 7 weeks observed in this study suggests that oxen underwent an adaptation to work during the first days of work. They became more adapted as work went on and they were therefore able to increase their intake. Bartholomew, Khibe and Little (1994) also attributed increases in speed of working teams over time to an adaptation to work. Therefore, working 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.

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 live weight 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. In order 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/100kg 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 draught force. The latter was set in this experiment to be proportional to the M of animals. Therefore any advantage of oxen in good condition over those in poor condition would have been expressed as a higher average walking speed. As compared 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 its fat content, generated the same power output. This suggests that power output is more dependent on body mass than 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 draught purposes. This may be constrained by the fact that more young animals are being used for draught purposes with a rapid on-farm turnover rate of these animals in many farming systems in sub-Saharan Africa, 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 the present study, oxen in 'poor' IBC sustained average draught forces of 682 N. These animals might not be able to perform ploughing or ridging for extended periods because these two activities require draught forces of about 820 N (Khibe and Bartholomew, 1990). 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 weeks while oxen were undergoing weight losses. The same trends in nve weight 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 oxen were able regain live weight at a rapid rate when they had access to good quality pasture during the rainy season in this experiment. It took them 4 to 6 weeks to reach their pre-work live weight.

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 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 not 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 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 6 weeks. If the working period is short, weight losses could be tolerated as animals will regain their live weight rapidly. Supplementary feeding is however worthwhile for animals scheduled to be sold for meat after work, even for short working periods, so that work does not adversely affect their market value. In semi-arid West Africa feed supplementation under these circumstances may be based on whole cotton seed, groundnut, sesame or cotton cakes if available. These feeds are rich in protein and energy and provide substrates (long chain fatty acids, glycogenic compounds) that can be directly used for work.

Acknowledgements

The authors thank the Overseas Development Adiministration (ODA) of the United Kingdom and the International Livestock Research Institute for funding this study.

References

Astatke, A., Reed, J.D. and Butterworth, M.H. 1986. Effect of diet restriction on work performance and weight loss of local Zebu and Friesian-Boran crossbred oxen. *ILCA Bulletin* **23**: 11-14.

Bartholomew, P.W., Khibe, T. and Little, D.A. 1994. Effect of liveweight and body condition on work output from draft oxen. *Tropical Animal Health and Production* **26**: 58-64.

Bartholomew, P.W., Khibe, T., Little, D.A. and Ba, S. 1993. Effect of change in body weight and condition during the dry season on capacity for work of draft oxen. *Tropical Animal Health and Production* **25**: 50-58.

Dicko, M.S. and Sangaré, M. 1984. De l'Emploi de la Traction Animale en Zone Sahelienne: Role de la Supplémentation Alimentaire. Document de Programme No. AZN 3. ILCA, Addis Ababa, Ethiopia.

Fall, A., Pearson, R.A. and Lawrence, P.R. 1996a. Nutrition of draught oxen in semi-arid West Africa I. Energy expenditure by oxen working animals of different circumstances. Animal Science (submitted).

Fall, A., Pearson, R.A., Lawrence and Fernández-Rivera, S. 1996b. Nutrition of draught animals in semi-arid West Africa II. Effect of work on intake, digestibility and ? of passage of food through the gastro-intenstinal tract in draught oxen fed crop residues. Animal Science (Submitted).

Faverdin, P., Baumont, R. and Ingvartsen, K.L. 1995. Control and prediction of feed intake in ruminants. In: *Recent Developments in the Nutrition of Herbivores.* (ed M. Journet, E. Grenet, M-H. Farce, M Theriez and C. Demarquilly), pp. 95-120. Proceedings of the IVth International Symposium on the Nutrition of Herbivores. INRA Editions, Paris.

Khibe, T. and Bartholomew, P.W. 1993. Recherches aux possibilités de conditionnement des boeufs de labour à base de paille de brousse enrichie à l'urée et évaluation de son impact sur leur capacité de travail. In: *Research for Development of Animal Traction in West Africa.* (ed P.R. Lawrence, K. Lawrence, J.T. Dijkman and P.H. Starkey), pp. 175-179. Proceedings of the Fourth Workshop of the West Africa Animal Traction Network, Kano, Nigeria, 9-13 July 1990. West Africa Animal Traction Network and International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Lawrence, P.R. and Pearson, R.A. 1985. Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science, Cambridge* **105**: 703-714.

Nicholson, M.J. and Butterworth, M. 1986. *A Guide to Condition Scoring of Zebu Cattle.* International Livestock centre for Africa (ILCA), Addis Ababa, Ethiopia. 36 p.

Pearson, R.A. and Lawrence, P.R. 1992. Intake, digestion, gastro-intestinal transit time and nitrogen balance in working oxen: studies in Costa Rica and Nepal. *Animal Production* 55: 361-370.

Pethick, D.W. 1993. Carbohydrate and lipid oxidation during exercise. *Australian Journal of Agricultural Research* **44:** 431-441.

Preston, T.R. and Leng, R.A. 1987. *Matching ruminant production systems with available resources in the tropics and sub-tropics.* Penambul Books, Armidale, Australia. 245 p.

SAS. 1985. SAS User's Guide. Statistics. SAS Institute Inc., Cary, NC, USA.

Wilson, R.T. 1987. Livestock production in Central Mali: Factors influencing growth and liveweight in agro-pastoral cattle. *Tropical Animal Health and Production* **19:** 103-114.

Table 1. **Daily intake (g/ kg M and g/ kg $M^{0.75}$) of millet stover over 7 weeks by oxen in 'poor', 'medium' and 'good' IBC on working and non working days.**

Sources of variation	Daily feed intake g/kgM		Daily feed intake g/kg$M^{0.75}$		Significance
Initial Body condition	Mean	s.e.	Mean	s.e.	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	Quad. ***
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:<0.001, NS: not significant

Table 2. **Speed (m/s) and power (W and W/100 kg M) for oxen in different initial body condition (IBC) over 7 weeks and during each lap around the circuit.**

Source of variation	Speed (m/s)	Power (W)	Power (W/100kg M)
Initial body condition			
'poor'	0.94	637	117
'medium'	0.86	637	107
'good'	0.96	780	118
s.e.	0.005	4	0.6
Lap			
	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
s.e.	0.08	6	
Week			
	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
s.e.	0.07	5	

Table 3. **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 7 weeks, 4 days per week.**

	Oxen in 'poor' IBC	Oxen in 'medium' IBC	Oxen in 'good' IBC
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
Live weight Change[4] (kg/day)			
calculated	-0.320	-0.370	-0.670
observed	-0.456	-0.308	-0.719

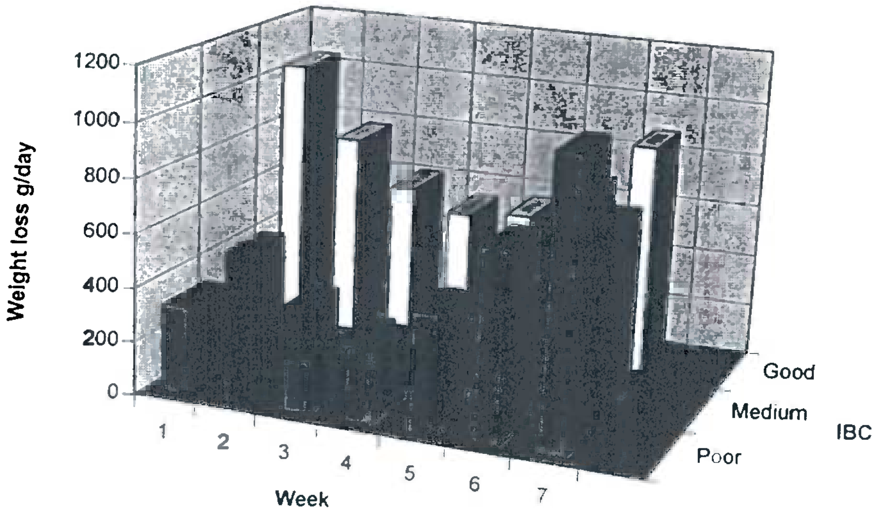
1: 8.05 MJ ME/kg DM

2; Energy used for maintenance = $(a\times b\times (0.53\times(M/1.08)^{0.67}))\times c$ (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 pulling loads. 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 Efficiency of doing work = 0.32 (Fall et al., 1996a)

4: 1 kg weight change ≡ 15 MJ NE.

Figure 1. Live weight losses over 7 weeks of work for oxen in initial poor, medium and good body condition (IBC)



Appendix 2

Short Title: *Draught ruminant energy expenditure*

The energy expenditure of cattle and buffaloes walking and working in different soil conditions

J.T. Dijkman[1†] and P.R. Lawrence[2]

Centre for Tropical Veterinary Medicine, Easter Bush, Roslin, Midlothian,
EH25 9RG, UK

SUMMARY

At the Centre for Tropical Veterinary Medicine, Scotland, during the summer months, two adult water buffaloes, two Brahman cattle and two Brahman x Friesian steers walked round a circular track on concrete or through 300 m deep mud. Average walking speed (m/s) when unloaded, or average walking speed (m/s) when pulling 324 N, energy for walking (J/m/kg) and net mechanical efficiency (%) were 1.05 and 0.81 ($P<0.01$), 1.03 and 0.80 ($P<0.001$), .49 and 3.34 ($P<0.001$) and 31.0 and 31.8 for concrete and mud respectively. Energy values were calculated from gaseous exchange measured with an open circuit system.

In Central Nigeria from September to May, the energy expenditure of eight Bunaji (White Fulani) bulls was monitored using portable oxygen measuring equipment (modified 'Oxylog') when walking, ploughing and harrowing on six soil surfaces ranging from hard, smooth earth to ploughed waterlogged clay. Average walking speeds (m/s), pulling speeds (m/s) and energy costs of walking (J/m/kg) varied from 0.97 - 0.65, 0.55 - 0.47 and 1.47 - 8.58 respectively. Net mechanical efficiency averaged 31.4 % and was unaffected by ground surface.

---

[1] Present address : Natural Resources Institute. Central Avenue, Chatham Maritime, Kent ME4 4TB, UK.

[†] To whom correspondence should be addressed.

[2] Present address: Institute for Animal Production, Hohenheim University (480), D-70593, Stuttgart, Germany.

The energy cost of walking for the *Bos indicus* cattle on smooth ground (1.47 J/m/kg) in this trial was less than that previously reported for *Bos taurus* (1.80 J/m/kg) and the reported average value for cattle (*Bos indicus* and *Bos taurus*) on treadmills (2.09 J/m/kg). The implications for practical agriculture of the higher levels of energy expenditure for walking in muddy conditions are discussed.

INTRODUCTION

The energy cost of walking and working in cattle and buffaloes has been extensively researched (Hall & Brody 1934; Ribeiro *et al.* 1977; Lawrence & Richards, 1980; Thomas & Pearson 1986; Lawrence & Stibbards 1990). Knowledge of the energy expenditure and quantification of the nutrient requirements of such animals, under as wide a range of conditions as possible, is necessary to develop more efficient ways of employing draught animals and of making the best use of feed resources available. The majority of these measurements were carried out while animals were walking and working on level, hard, dry surfaces of a treadmill or circular race. Values obtained under these conditions have subsequently been used in a factorial method to estimate the energy expenditure and the ensuing nutritional requirements of animals working in the field (Lawrence 1985, 1987; Mathers 1984; Graham 1985; Mathers *et al.* 1985). Animals working on farms, however, seldom operate under these conditions.

White & Yousef (1978) first reported on the extra energy expended on different terrain as the energy expenditure for walking in reindeer increased significantly (24 %) in the change from dry to wet tundra. Energy consumption connected with walking can make up for 40-60 % of the total energy expenditure when draught animals are working on hard surfaces. An increase in the energy cost of walking under adverse conditions means that animals have less energy available to do useful work. In addition, it is likely that the use of the laboratory based values in a factorial method can cause significant errors in the estimation of draught animal energy expenditure in the field.

This paper presents the results of two experiments set up to investigate the increase in energy expenditure for the various tasks that animals perform in the field associated with varying conditions underfoot. Initial investigations were carried out at the Centre for Tropical Veterinary Medicine (CTVM), Edinburgh, United Kingdom, during the summer months of 1987, where animals walked and worked in 300 mm deep mud in a circular track and these results were compared with the results obtained while the animals performed the same tasks when the track was not covered in mud. Additional experiments were done during the work of the International Livestock Research Institute (ILRI) on the introduction of animal traction into inland valleys in Kaduna, Nigeria, from September 1991 to May 1992. Seasonally inundated low-lying valleys or fadamas, which make up *c.* 7 % of the total cultivable area of Africa, are an important feature of agriculture in the sub-humid zone of Africa (ILCA 1990). The valley bottoms are formed by the accumulation of fine soil particles. They are flat with a high clay or very fine sand content and inclined to be waterlogged. In contrast the surrounding soil (known as the uplands), from which the fine particles are washed, is coarse and gritty though still fairly fertile. In Nigeria, the valley bottoms are used almost exclusively by small-scale farmers for rice production and by peripatetic Fulani herdsmen as a source of winter grazing for their cattle. The uplands are used principally for the production of food crops such as maize and sorghum. Until recently, animal traction had been restricted to the Northern Sahelian zone of Nigeria, but with the decline of the tsetse challenge, ILRI commenced work on the introduction of animal traction into the sub-humid zone. During this work it became apparent that the consistency of the soil had a profound effect on the energy consumption of working animals. Hence the ILRI project-site offered an excellent place to investigate the issue.

The paper draws some general conclusions which should enable a more efficient and rational use of draught animals, provide basic information on food requirements and assist in the design of animal-drawn implements.

MATERIALS AND METHODS

Experiment 1

Animals and feeding

Six animals were used, two water buffaloes (*Bubalus bubalis),* two Brahman cattle (*Bos indicus)* and two Brahman x Friesian steers (Table 1). All animals had been trained from 1 year old and were familiar with the experimental procedures. During the experimental period they were fed a diet of medium quality hay calculated to provide maintenance energy requirements in two equal meals at 08.00 and 16.00h daily.

[insert Table 1]

Experimental procedure

Energy expenditure measurements were made while a single animal was in a circular race which consisted of two circular and concentric brick walls 610mm high having radii of 3 and 5m. When working, the animals pulled on a radial arm made of galvanized steel tube 100mm diameter and 4.5m long. Where the arm passed over the inner wall, it was attached to a trolley made of angle iron which ran along the top of the wall on castors and included the hydraulic braking mechanism and a seat for the person in charge of the animals. At the centre of the race, the radial arm was attached via two pillow block bearings to a vertical spindle made of 75mm diameter mild steel.

The gaseous exchange of the animals was measured using an open circuit gas analysis system (Lawrence *et al.* 1991). The animals under investigation wore a loose fitting face mask through which air was drawn at a constant rate chosen so that the maximum CO_2 concentration in the air leaving the mask approached but never exceeded 1.0%. Samples of inspired and mixed expired air were analysed for CO_2 increment and O_2 decrement and the results logged continuously into a modified personal computer. Energy consumption during any period was calculated using factors drawn up by Brouwer (1965) as:-

O_2 consumption (l at Standard Temperature and Pressure (STP)) x 16.16 + CO_2 consumption (l at STP) x 5.09

No corrections were made to this formula to allow for methane production or the excretion of urinary nitrogen, as these factors are of little quantitative importance (Lawrence & Pearson 1985)

Air was drawn through the mask via a 5 cm. diameter hose by a multistage centrifugal pump driven by an induction motor (Air Control Products, Chard, Somerset). The air flow rate was measured by a rotameter. Both pump and rotameter were attached to a horizontal wooden platform in the centre of the race which revolved with the main radial arm. A specially designed swivel was made to enable the electricity supply to reach the pump when the animals were walking round the race without tangling the cables. Another part of the same device allowed continuous removal of a sample of mixed expired air to the gas analysers, which were housed in a nearby laboratory.

While in the circular race, animals either stood still, walked round at a steady speed without a load, or walked at a steady speed while pulling against a hydraulically activated loading system. During the latter operation, the work done by the animals was measured using an ergometer (Lawrence & Pearson 1985), which also measured the distance travelled. The force required to move the trolley against the resistance produced by the hydraulic braking system varied little between trials. The average value for all trials (324 ± 10N) was used in all subsequent calculations of work and power outputs.

When walking without a load, the animals were encouraged with verbal commands by someone walking inside the inner wall of the circular race slightly behind and to the left of the animal. When the animals pulled a load, the person was in approximately the same position relative to the animal but was seated on the trolley which contained the hydraulic braking system. The animals were thus continually encouraged to walk but were never beaten or goaded.

The respiratory exchange of each animal was measured for 20 min for each of the three types of activity and the results from the final 10 min used for subsequent calculations of energy expenditure. Inspection of the continuous records of gaseous exchange produced by the data-logging system showed that animals always reached a steady rate of energy expenditure after the first 10 min of a 20 min period when they were walking or pulling loads.

In any particular measuring session, an animal would stand, walk, pull and stand. The two standing values of energy consumption were averaged. Each animal was first tested for four sessions while walking on concrete. The circular race was then filled with mud to a depth of 300 mm for a further four sessions per animal. Finally the mud was removed and the four sessions on concrete were repeated.

No animal was used for more than two sessions in one day. The complete series of measurements was carried out over a period of 9 weeks.

Measurements were taken during the last 10 min of each part of each session as described above and the following data recorded:- distance walked without load (m), distance walked with load (m) and the energy expended when standing still, walking and pulling (J). From these data were derived the energy cost of walking and the net mechanical efficiency of the animal defined as:-

Energy cost of walking (Ew) (J/m/kg liveweight) =

$$\frac{\text{energy used while walking (J) - energy used while standing still(J)}}{\text{distance walked without load (m) x liveweight (kg)}} \qquad (1)$$

The calculation of net efficiency was rather more complicated because the animals walked at different speeds when walking unloaded and pulling.

Net efficiency (%) =

$$\frac{\text{work done (J)} \times 100}{\text{energy used while pulling (J)} - \text{energy used while standing (J)} - (\text{Ew} \times \text{liveweight} \times \text{distance travelled with load})\text{(J)}} \quad (2)$$

(Lawrence & Stibbards 1990)

Statistical analysis of the results consisted of an analysis of variance using GENSTAT 5 (Genstat 5 Committee 1987), which compared walking speeds (loaded and unloaded), energy cost of walking and mechanical efficiency between individual animals, type of animal (buffalo, Brahman or Brahman cross) and surface (initial concrete, mud or final concrete). There were four replicates for each combination of animal and surface giving a total of 72 sets of results.

Experiment 2

Animals and feeding

A total of eight Bunaji bulls (*Bos indicus*) were used in the initial upland walking trials of the Nigerian experiments. Subsequent measurements were carried out using six animals only, because one pair of bulls was not completely trained for cultivation work. All experimental determinations were made at Kufana village, 80 km south east of Kaduna in the sub-humid zone of Nigeria, from September 1991 to May 1992. The animals in Kufana were used throughout the year for cultivation, weeding and transportation for the ILRI project and had been in constant use over the past three years. The ages, weights and pairing of the animals are shown in Table 2

The animals were fed 3 kg of concentrates each at 06.00 h (one hour before the start of the experiments) to ensure that they were mainly metabolising carbohydrates during the experimental periods. Hence, the value of the respiratory quotient (RQ) probably varied between 0.8 and 1.0 during the experimental period. The animals had continuous access to natural pasture, water and a salt lick. Ambient temperatures throughout the experimental period ranged between 22 and 31°C with the relative humidity ranging between 0.30 and 0.85.

[insert table 2]

Experimental methods

Recent adaptation and validation of the Oxylog, which was originally designed for use with human beings (Humphrey & Wolff 1977), for use with draught animals (Lawrence *et al.* 1991; Dijkman 1993) has made it possible to measure accurately the O_2 consumption of animals working in the field. The Oxylog (P.K. Morgan Ltd, Kent, UK) uses a turbine flow meter mounted on the inlet side of the face mask. After each breath a small reciprocating pump takes samples of air entering and leaving the mask. The samples are passed into separate reservoirs containing a solid desiccant which give 'running average' O_2 concentrations which are measured using two polarographic O_2 electrodes linked differentially. The electronic system calculates and displays total O_2 consumption and total volume of inspired air at STP after making corrections for atmospheric temperature, pressure and humidity. Other functions allow the display of O_2 partial pressure difference between the inlet and outlet, and minute volumes of O_2 consumption and airflow.

Several adaptations were necessary in order to use the Oxylog for oxen. Firstly a mask was made to fit oxen which incorporated a saliva trap and allowed the animal to be guided either by a halter or by a nose ring. The seal consists of an annular cuff of 1 mm thick natural rubber which seals perfectly at a point just behind the animal's nose when the mask is pushed onto the face. The basic frame of the mask is made from 10 mm plywood and is of a geometrically simple shape. This means that new masks to fit animals of different sizes can be made quickly, easily and cheaply.

Secondly, larger versions of the turbine flow meter were made. It was found possible to make scaled up versions of this type of flow meter which gave good linear responses when calibrated using a reciprocating pump operated at different speeds to give a range of flow rates. The capacity of the inlet and outlet valves was increased simply by increasing their number from one to three and nesting them in a larger tube. Finally, the tube connecting the mask to the Oxylog was fitted with a bypass so that only a fraction of the air passed the sampling point (Plate 1).

[insert Plate 1]

The animals were trained to wear the facemask, to carry the analysing and recording unit of the Oxylog and to the general experimental routine over a period of four weeks. This was essential to obtain high acceptance rates of the mask (in this case 100%) and to ensure that the animals breathed and worked normally while wearing the instruments. During the first 2 weeks of training, each animal wore a dummy mask for 30 min/day. Ballast equivalent to the weight of the Oxylog was placed in the Oxylog pouch on the girth strap to balance the counterweight. In the third and fourth week of training, animals were fitted with the complete Oxylog instrumentation and facemask. Each animal was trained for 45 min/day. Respiration rate/min, before and after the fitting of the facemask, was checked at the start of all experiments and no differences were found in any of the experimental animals.

During the experiments animals walked and worked in pairs, as during the normal working routine of the farmers on the farm, and wore a neck yoke. The wearing of the Oxylog apparatus was rotated on a daily basis.

The measurements were made on three soils with different consistency: upland (firm, an animal does not sink into the soil), dry fadama (an animal sinks 50 - 250 mm into the soil), wet fadama (an animal sinks > 250 mm)

Both the modified Oxylog and ergometer (Lawrence & Pearson 1985) were used to monitor the performance of the animals enabling measurements of O_2 consumption (l), ventilation volume (l), and where applicable distance travelled (m) and work done (J). Because the

Oxylog displays are very small and difficult to read, a panel with two voltmeters, giving the readings for minute O_2 consumption and minute ventilation volume, and two digital counters, recording total O_2 consumption and total ventilation volume, was manufactured. This data viewing panel was connected to the recorder output on the Oxylog via a long cable, hence facilitating the manual 'data logging'

Implements were connected to the middle of the yoke by a chain, with a load cell (Type 241 by Novatech Ltd, Hastings, UK, 0-3000N) fitted between the implement and chain, so that all the force produced by the animals was channelled through the load cell. Hence the work done per animal was obtained by dividing the measured values by two. Distance averaged draught force (DADF) was calculated by dividing the work done by the distance walked.

All parameters were recorded every minute on the minute. During a typical experiment each animal went through the following routine:-

(a)	Rest	20 min
(b)	Walk	20 min
(c)	Work (i.e. pulling)	60 min (three times 20 min)
(d)	Walk	20 min
(e)	Rest	20 min

Each activity was monitored for at least 20 min. This ensured that the animal reached a metabolic 'steady state' before the energy consumption associated with each particular activity was measured, and it allowed for the response time of the Oxylog. In well-fed animals, energy expenditure during each activity can be calculated by multiplying the average O_2 consumption (l/min) by 20.7 kJ (Brouwer 1965).

To enable continuous movement, the animals both walked and worked in large circles (minimum diameter 30 m). Animals were allowed to choose their own walking/working speed, but this was then maintained throughout the measurement period. Ew and the net mechanical efficiency of the animals were defined as in Eqns (1) and (2) respectively. The energy costs for both standing and walking were taken as the average of the first and final measurement.

Whilst ploughing, the lead animal walked on land which had already been ploughed and when harrowing both animals walked on ploughed land. This had a significant influence on the energy expended for walking. It was therefore decided to divide Ew into $Ew_{unploughed}$ and $Ew_{ploughed}$ for the three soil consistencies investigated. As in Expt 1, several separate measurements (in this case 3-5) for each animal for each activity were averaged to provide the single data points which were used in the analysis of variance of the results using GENSTAT 5 (Genstat 5 Committee 1987).

RESULTS

Experiment 1

Initial analysis showed that there was no significant difference for any of the measured parameters between the two individuals in each group of animals. Similarly, there was no significant difference between groups of animals, though there was a tendency for buffaloes to use more energy for walking on concrete than the other animals and for the Brahman cattle to walk faster than other animals, whether with or without a load (Table 3).

[insert Table 3]

There were also differences in the performances of the animals on concrete before and after they worked in mud. During the second trial on concrete (concrete 2), the animals walked significantly faster when pulling a load (1.13 *v.* 0.92m/s, $P<0.001$), than during the first trial on concrete (concrete 1). They also walked faster when unloaded and had a lower energy cost of walking during concrete 2 in comparison with concrete 1 (Table 3). The difference between the energy cost of walking for concrete 1 and concrete 2 (1.69 *v.* .29 J/m/kg, $P=0.073$), almost reached significance at $P<0.05$. The better performance of the animals during concrete 2 probably means that they were fitter after having already worked for 6 weeks during the first trial on concrete and in mud.

Combination of the results for concrete 1 and 2 for all animals gives values of 1.05 and 1.03 for average walking and pulling speed (m/s), 1.49 for the energy cost of walking (J/m/kg) and 31.0 for the net mechanical efficiency (%). 300mm deep mud significantly lowered walking ($P<0.01$) and pulling speed ($P<0.001$), in comparison to walking and pulling speed on concrete. In addition, the energy cost of walking in 300mm deep mud showed a significant increase of 220 % ($P<0.001$) from the energy cost of walking on concrete. The net mechanical efficiency at *c*. 30 % was not affected.

Experiment 2

Pair A and B of the experimental animals (Table 2) were ready for experimental observations after 2 weeks of training. Pair C and D of the experimental animals, however, took substantially more time and patience to train. Nevertheless, at the end of the 4-week training period all experimental animals were fully accustomed and at ease with the experimental procedures and the wearing of the facemask.

Analysis showed that there was no significant difference for any of the measured parameters between the two individuals in each pairing. Similarly there was no significant difference between pairs, although pair C walked significantly faster during work on all soil consistencies ($P<0.05$).

There was a general tendency for Ew to increase significantly ($P<0.001$)in the change from unploughed to ploughed conditions underfoot. $Ew_{\text{ploughed upland}}$, which averaged 2.87 J/m/kg, meant an increase of 195 % from $Ew_{\text{unploughed upland}}$. Similarly, $Ew_{\text{ploughed dry fadama}}$, which averaged 3.76 J/m/kg, showed an increase of 214 % from $Ew_{\text{unploughed dry fadama}}$. In the case of

$Ew_{\text{ploughed wet fadama}}$, which averaged 8.58 J/m/kg, the situation was even more extreme as this meant an increase of 260 % in the change from unploughed to ploughed conditions (Table 4).

In conjunction with the general increase in the energy expended for walking, walking speed showed a general decline with a reduction of the consistency of the soil. Walking speed decreased significantly ($P<0.01$) in the change from unploughed to ploughed conditions on all soils investigated. The most significant decrease ($P<0.001$) was observed on the wet fadama, where walking speed reduced by nearly 19 % (Table 4).

[insert Table 4]

The net mechanical efficiency for ploughing and harrowing was not significantly affected by the conditions underfoot and varied between 30.2 and 32.7 % (Table 5). The DADF was significantly lower on all soils ($P<0.001$ for upland and wet fadama; $P<0.01$ for dry fadama) while animals were harrowing. Pulling speed, however, was only significantly affected ($P>0.01$) on the upland (Table 5).

[insert Table 5]

DISCUSSION

The differences in animal performance between the two trials on concrete in Expt although not significantly different, emphasise the fact that it is essential in experiments of this kind to use animals which are well-trained not only in the sense of being easy to handle and tractable, but which have also attained a high and consistent level of physical fitness. In this study it was not possible to apply the usual statistical remedy to problems of this kind by applying the treatments at random, because filling the circular race required an estimated 20 tonnes of semi-liquid mud which could not be taken in and out easily.

The average energy cost of walking on concrete in Expt 1 (1.49 J/m/kg liveweight) was lower than the value obtained by Lawrence & Stibbards (1990), using the same measuring system, for animals walking on treadmills (2.09 J/m/kg for Brahman cattle and buffaloes) and slightly higher than the value for 'free' animals walking on beaten earth in Expt 2 (1.47 J/m/kg liveweight).

Comparison of these results with general formulae proposed by Tucker (1969) and Taylor *et al.* (1970) to predict the energy cost of locomotion, using, for example, an average liveweight of 387 kg for the animals in Expt 2, gives values of 3.3 J/m/kg and 1.0 J/m/kg respectively. As pointed out by Lawrence & Stibbards (1990), the measurements on which Tucker based his formula included the resting metabolic rate. This in conjunction with the fact that animals have, on average, a standing metabolic rate which is 26% higher on working days than on non-working days (Lawrence *et al.* 1989), lends more support to Tucker's (1969) higher estimate. King (1981) proposed a general formula for the energy expenditure of walking in Zebu cattle of 200 kg, fed at maintenance. He based his formula for the energy expenditure on the walking speed. Substitution of the average walking speed on unploughed upland (0.97 m/s) in Expt 2 gave a value of 15 J/m/kg, which was probably the best prediction of the three formulae considered.

The higher values obtained for Ew by Lawrence & Stibbards (1990) in the laboratory setting can be explained by the fact that during these types of experiment animals are forced to walk at a certain speed on a moving treadmill surface and probably spent energy balancing and slipping. In the present experiments animals were allowed to choose their own walking speed, which was then maintained throughout the measurement period.

In recently published work, using a collection bag portable 'breath by breath' analyser, average walking values for German Simmental and Niger Zebu were respectively 1.84

J/m/kg and 1.03 J/m/kg (Clar 1991) and 1.75 J/m/kg and 1.45 J/m/kg (Rometsch 1995). Whereas the values obtained for Niger Zebu are in relative agreement with the current study, the average cost of locomotion observed in the German Simmentals is substantially higher. The Simmentals in the former studies were fed at 1.5 maintenance and were fat, whereas the Zebus were fed at maintenance and were thin. It is hypothesised that herein lies a possible explanation for the observed differences. The energy cost of carrying applied loads is greater than the energy costs of walking especially when the load is placed on the middle of the back (Lawrence & Stibbards 1990). This would help explain the difference between fat and thin animals and also the apparent difference between *Bos indicus* and *Bos taurus*. *Bos indicus* carries its fat (when it has any) efficiently over its shoulders whereas *Bos taurus* carries it around the gut, which places strain on the spine and tends to impede its gait

A crucial observation in Expt 2 was that the Ew on ploughed land doubled or more than doubled. These observations have nutritional implications for draught animals working on soils of differing consistencies. When animals were ploughing with a mouldboard plough, the lead animal walked on land which had already been ploughed and as a result spent between 20 and 25 % more energy than its partner while doing the same job. Moreover, the walking speed went down as the energy expenditure for walking went up. These results were consistent with the results from Expt1, where we observed a 124 % increase in energy expenditure for walking when animals changed from walking on concrete to walking in 300 mm mud.

In the walking experiments a decrease in soil consistency was linked to a decrease in walking speed and an increase in the energy expenditure for walking, but the situation when animals are ploughing or harrowing is slightly more complicated. Whereas the same trend of animals slowing down on the wetter soils can be observed, other factors which have an impact on the walking speed during work are the type of implement and the draught force needed for the specific cultivation.

Although animals will spend approximately the same amount of energy during a full working day (Lawrence 1985), whether they are doing 'light' or 'heavy' work, the energy expenditure per unit area and the actual cultivation time needed will be much higher. When animals are employed for part of the day only, the extra energy expenditure of the lead animal while ploughing has to be taken into account. When animals are harrowing, both animals will spend more energy for walking, and as a result less energy will be available during the working day for doing useful work.

The efficiency of doing work in Expt 2 was not influenced by the consistency of the soil. These results were again consistent with results in Expt 1. This however, was expected, as to obtain the efficiency of doing work the real energy cost for walking was subtracted from the extra energy expended during work. The fall in efficiency observed by Lawrence & Smith (1988), when animals were working on muddy soils in Costa Rica, was likely to be caused by an increase in Ew. Overall, the mechanical efficiencies measured were in the same range as the values reported for Brahman cattle, although substantially lower than the mechanical efficiency of buffaloes (Lawrence & Stibbards 1990). Mechanical efficiency reported by Agricultural Research Council (ARC 1980) and Thomas & Pearson (1986) were also 3-4 % higher.

During ILRI's work, pilot trials have shown that it was possible to plough and harrow a large proportion of the fadama area in Kufana during the dry season using ox-drawn implements, whereas in all but a few places the soil was too hard for manual cultivation until the onset of the rains. Ox-drawn cultivation in the dry season had several advantages. Time was not a constraint and cultivation could be done more thoroughly. Working conditions were less stressful because it was dry and cool. The exposure of the soil to the winter sunshine killed a lot of the pests and weeds. Most important of all, the rice crop could be sown in the fadama as soon as sufficient rain had fallen and the farmers could devote all their time and energy to the cultivation of their upland food crops. The present results, further point out that it would make sense to cultivate the fadama soils in the dry season from an animal point of view. Not only are the animals likely to be in a better condition at that time of the year (Smith 1981), but also the soil is not too wet and, hence, Ew will be lower which leaves more energy for doing useful work. Not only Ew increased as soils got further inundated with water, but also the DADF rose quite substantially. As a result more time, effort and energy was needed to cultivate a unit area. Although a system of dry season cultivation can be appropriate and more efficient from our scientific point of view, the implications of the actual implementation of such an idea will need careful consideration. For a start, fadamas constitute one of the main dry season grazing reservoirs for the cattle of the peripatetic Fulani herdsmen and cultivation of these inland valleys during the dry period would restrict their use for grazing.

Our sincere thanks are due to I. Campbell and R. Archibald for their technical support at the Centre for Tropical Veterinary Medicine. The financial support from the International Livestock Research Institute during the work in Nigeria and the use of their facilities is highly acknowledged. Personal thanks are deserved by H. Fitzhugh and D. Little and all the ILRI Kaduna field staff.

REFERENCES

Agricultural Research Council (1980). *The Nutrient Requirements of Ruminant Livestock* Farnham Royal, Slough: Commonwealth Agricultural Bureaux.

Brouwer, E. (1965). Report of the sub-committee on constants and factors. In *Proceedings of the Third Symposium on the Energy Metabolism of Farm Animals. EAAP Publication No. 11* (Ed. K. L. Blaxter), pp. 441-443. London: Academic Press.

Clar, U. (1991). *Entwicklung einer feldmethode zur messung des energie umsatzes bei zugtieren*. PhD thesis, University of Hohenheim.

Dijkman, J. T. (1993). *The measurement of draught ruminant energy expenditure in the field.* PhD thesis, Centre for Tropical Veterinary Medicine, University of Edinburgh.

GENSTAT 5 COMMITTEE (1987). *Genstat 5 Reference Manual.* Oxford: Clarendon Press.

Graham, N. Mc. (1985). Relevance of the British metabolisable energy system in the feeding of draught animals. In *Draught Animal Power for Production* (Ed. J. W. Copland), pp. 96-98. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Hall, W. C. & Brody, S. (1934). The energy cost of horizontal walking in cattle and horses of various ages and body weights. University of Missouri Agricultural Experiment Station, *Research Bulletin* 208.

Humphrey, S. J. E. & Wolff, H. S. (1977). The Oxylog. *Journal of Physiology* **267**, 12.

International Livestock Centre for Africa (1990). *Annual Report and Programme Highlights*. Addis Ababa, Ethiopia: ILCA.

King, J. M. 1981. *Ungulate Water Turnover in Tropical Africa*. Monograph No. 6. Addis Ababa, Ethiopia: ILCA.

Lawrence, P. R. (1985). A review of the nutrient requirements of draught oxen. In *Draught Animal Power for Production* (Ed. J. W. Copland), pp. 59-63. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Lawrence, P. R. (1987). Nutrient requirements of working ruminants. In *An Introduction to Working Animals* (Ed. J. L. Falvey), pp. 61-79. Melbourne: MPW Australia.

Lawrence, P. R. & Pearson, R. A. (1985). Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science, 0Cambridge* **105**, 703-714.

Lawrence, P. R. & Richards, J (1980). The energy cost of walking in some tropical draught animals. *Animal Production* **30**, 455.

Lawrence, P. R. & Smith, A. J. (1988). A better beast of burden. *New Scientist* **1609**, 49-53

Lawrence, P. R. & Stibbards, R. J. (1990). The energy cost of walking carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffaloes. *Animal Production* 50, 29-39.

Lawrence, P. R., Sosa, R. & Campbell, I. (1989). The underlying 'resting' energy consumption of oxen during work. *Proceedings of the Nutrition Society* 48, 154A

Lawrence, P. R., Pearson, R. A. & Dijkman, J. T. (1991). Techniques for measuring whole body energy expenditure of working animals: A critical review. In *Isotope and Related Techniques in Animal Production and Health*, pp. 211-232. Vienna: International Atomic Energy Agency.

Mathers, J. C. (1984). Nutrition of draught animals. In *Animal Energy in Agriculture in Africa and Asia*, pp. 60-66. FAO Expert Consultation on Appropiate Use of Animal Energy in Agriculture in Africa and Asia, 15-19 Nov. 1982. FAO Animal Production and Health Paper 42. Rome: FAO.

Mathers, J. C., Pearson, R. A., Sneddon, J. C., Matthewman, R. W. & Smith, A. J. (1985). The use of draught cows in agricultural systems with particular reference to their nutritional needs. In *Milk Production in Developing Countries* (Ed. A. J. Smith), pp. 476-496. Edinburgh: Edinburgh University Press.

Ribeiro, J. M. DE C. R., Brockway, J. M. & Webster, A. J. F. (1977). A note on the energy cost of walking in cattle. *Animal Production* 25, 107-110.

Rometsch, M. (1995). *Energieumsatz und herzfrequenz von zugochsen*. PhD thesis, University of Hohenheim.

Smith, A. J. (1981). Role of draught animals in agricultural systems in developing countries. In *Vegetable Productivity* (Ed. C. R. W. Spedding), pp. 247-262. London: Macmillan Publishers Ltd.

Taylor, C. R., Schmidt-Nielsen, K. & Raab, J. L. (1970). Scalling of energetic cost of running to body size in mammals. *American Journal of Physiology* **219**, 1104-1107.

Thomas, C. K. & Pearson, R. A. (1986). Effect of head cooling on energy expenditure, feed intake and heat tolerance of Brahman and Brahman x Friesian cattle working on treadmills. *Animal Production* **43**, 83-90.

Tucker, V. A. (1969). Energetic cost of locomotion in animals. *Comparative Biochemistry and Physiology* 34, 841-846.

White, R. G. & Yousef, M. K. (1978). Energy expenditure in reindeer walking on roads and on tundra. *Canadian Journal of Zoology* 56, 215-223.

Table *Species, sex, ages and weights of animals used in Expt 1*

Species/breed	Sex	Age (years)	Liveweight range (kg)
Bubalus bubalis	male castrate	10	825-850
Bubalus bubalis	male castrate	9	770-800
Bos indicus	male castrate	9½	610-625
Bos indicus	female	3	370-400
Brahman x Friesian	male castrate	4½	625-675
Brahman x Friesian	male castrate	4½	645-695

Table 2. *Species, ages and weights of animal pairs used in Expt 2*

Species/Breed	Age (years)	Liveweight range (kg)	Pair
Bos indicus	7	375-440	A
Bos indicus	7	385-440	
Bos indicus	5½	310-360	B
Bos indicus	5	380-430	
Bos indicus	4½	350-395	C
Bos indicus	4	305-355	
Bos indicus	6	385-430	
Bos indicus	6	335-380	D*

*Animals only used for 'walking upland'.

Table 3. *Walking speed when unloaded, walking speed when pulling an average load of 324 N, energy cost of walking and mechanical efficiency of draught animals on two different surfaces during Expt 1*

Surface	Animal	Walking speed (m/s)	Pulling speed (m/s)	Energy for walking (J/m/kg)	Mechanical efficiency (%)
Concrete 1	Buffalo	0.90	0.83	1.85	31.0
	Brahman	1.13	1.04	1.57	26.0
	Brahman x	0.94	0.90	1.65	31.9
Mud	Buffalo	0.78	0.77	3.56	36.1
	Brahman	0.95	0.92	2.89	29.1
	Brahman x	0.69	0.72	3.57	30.1
Concrete 2	Buffalo	1.01	1.06	1.56	28.1
	Brahman	1.23	1.26	1.27	35.5
	Brahman x	1.06	1.06	1.05	33.7
S.E.M. (9 D.F.)		0.07	0.07	0.19	2.8
Concrete 1	All animals	0.99	0.92	1.69	29.6
Mud	All animals	0.81	0.80	3.34	31.8
Concrete 2	All animals	1.10	1.13	1.29	32.4
S.E.M. (15 D.F.)		0.05	0.05	0.12	1.7

Table 4. *The energy cost and speed of walking of Bunaji bulls on ploughed or unploughed soils of different consistency in the sub-humid zone of Nigeria during Expt 2*

Soil	n	Walking speed (m/s)	Energy for walking (J/m/kg)
Unploughed upland	8	0.97	1.47
Ploughed upland	6	0.83	2.87
Unploughed dry fadama	6	0.87	1.76
Ploughed dry fadama	6	0.74	3.76
Unploughed wet fadama	6	0.80	3.30
Ploughed wet fadama	6	0.65	8.58
S.E.M., n=8 (32 D.F.)		0.07	0.22
S.E.M., n=6 (32 D.F.)		0.06	0.26

n = number of animals

Table 5. *Walking speed when pulling, mechanical efficiency and DADF of Bunaji bulls ploughing and harrowing on soils of different consistency in the sub-humid zone of Nigeria during Expt 2 (mean values for 6 animals)*

Activity	Pulling speed (m/s)	Mechanical efficiency (%)	DADF (N)
Ploughing upland	0.55	31.8	658
Harrowing upland	0.66	32.7	779
Ploughing dry fadama	0.53	30.2	1130
Harrowing dry fadama	0.51	32.3	1250
Ploughing wet fadama	0.46	30.5	1265
Harrowing wet fadama	0.47	31.1	1450
S.E.M. (30 D.F.)	0.04	1.4	63

DADF = distance average draught force.

Appendix 3

ENERGY REQUIREMENTS OF WORKING EQUIDS

R.A. PEARSON

Centre for Tropical Veterinary Medicine,
University of Edinburgh

INTRODUCTION

While it is important to understand how equids process and digest the feed they are provided with, it is equally important to know how much of this feed should be given to maintain health, fit animals. Most equids with the exception of breeding animals are kept for sport, leisure or work. Considerable effort has been put into understanding the feed requirements of racehorses and sports horses in developed countries over the last two decades (e.g. Pagan and Hintz, 1986a,b). However, the energy needs of working equids have not received the same attention, although horses and ponies are still used in many parts of the world for transport and work. Information on energy requirements for work is largely limited to the studies of Brody (1945) on large draught horses in temperate areas. He suggested increasing maintenance requirements by proportionally 0.10 for 1 h of field work (Brody, 1945). Recent observations in Chile suggest that this may be an underestimate when large draught horses (650 kg) are carting loads and values of 2.4 x maintenance over an 8 h working day have been estimated to more truly reflect requirements. Information on small working horses and ponies is largely anecdotal.

Donkeys play a major role as working animals in the semi-arid and mountainous areas of Africa, Asia and Latin America. Compared with the data on cattle and buffalo, the most numerous draught animals in the tropics, until recently (e.g. Dijkman, 1992) little information was available on requirements of donkeys for work or their working efficiency. Recently Dijkman (1992) found that donkeys were more efficient in both carrying and pulling loads in laboratory studies than oxen and buffaloes.

The work described in this section was undertaken to provide more information on the energy requirements of donkeys and small horses for walking and work (pulling and carrying loads).

PART ONE Laboratory studies

INTRODUCTION

Studies of small ponies were undertaken in the laboratory using a treadmill to regulate work and an indirect open-circuit calorimetry system to measure oxygen consumption and carbon dioxide production (Plate 1).

Two experiments were carried out. In the first one the effect of speed of walking on the energy cost of walking in ponies was investigated. Shetland ponies were studied when walking at four different speeds on a treadmill. In the second experiment the effect of size of load on the energy cost of pulling in Shetland ponies was determined. Energy costs of pulling loads equivalent to 5, 10 and 15 kg df/ 100 kg live weight were determined in Shetland ponies. Values for the energy used for standing and walking were also obtained in this experiment.

MATERIAL AND METHODS

Animals and their Management

Experiment One

In experiment one, four mature male Shetland ponies (live weight 110-230 kg) were loose-housed and fed hay and concentrates to maintain live weight. The ponies were exercised daily as a group by loose-schooling at all paces for approximately 30 mins. They were trained to walk on a level treadmill at speeds of 0.35, 0.63, 0.86 and 1.13 m/s. The ponies were tethered while on the treadmill. However they walked readily and maintained slack lead ropes at all times.

Experiment Two

Five mature male Shetland ponies (live weights 160-230 kg), including the four used in the previous study, were used. The animals were kept on good pasture and received 350 g concentrate supplement on working days. During a 4-week period at the start of the experiment, the ponies were trained to pull loads while walking on the treadmill at a speed of 1.1 m/s, before any measurements were made. The ponies wore a breastplate harness when pulling. Loads were provided by weights suspended in a metal frame behind the treadmill and connected to the pony's harness via a chain and a system of pulleys (Lawrence and Stibbards, 1990).

Measurements

Distance travelled on the treadmill was calculated by multiplying the known length of the treadmill belt by the number of revolutions.

The oxygen consumption and carbon dioxide production of the animals were determined using the open-circuit calorimetry system described by Richards and Lawrence (1984) modified as described by Lawrence (1989). The animals were allowed to reach a steady state of energy consumption which usually took 5 to 10 min, whereupon measurements continued for a further 15 min. In this way it was possible to obtain the energy consumption associated with the particular activity.

During measurements the following routine was used: Experiment One - standing, walking at a constant speed, standing, walking at the same speed. The measurements were replicated six times for each pony at each speed. Experiment Two: standing, walking, pulling at one of the load levels, walking, standing. Each of the three load treatments was replicated five times on each pony, with no load treatment being repeated consecutively on a pony.

Plate 1. Measurement of oxygen consumption and carbon dioxide production in a pony exercising on a treadmill in a laboratory

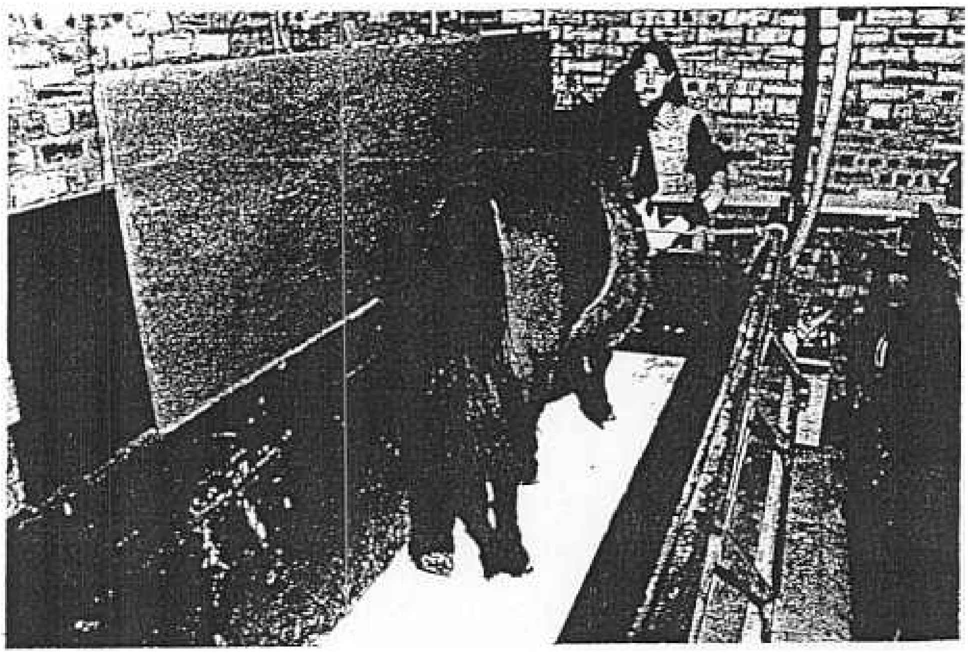


Plate 2. Measurement of oxygen consumption of a donkey using a modified oxylog in field studies in Africa

The rate of energy expenditure for standing and for walking were expressed per kg live weight. The net energy costs of walking and for pulling were also calculated. It was assumed that the energy required to support the body whilst walking or pulling was equivalent to that needed to support the body whilst stationary. Therefore the energy cost of walking (J/m walked per kg live weight)= [energy used while walking - energy used while standing still]/[distance walked (m) X live weight (kg)]. The energy cost of pulling loads (J/m walked per kg pulled)= [energy expended when pulling a load - energy expended to walk the same distance unloaded at the same speed]/[distance walked (m) X load pulled (kg)]. The efficiency of doing work was defined as the work done/energy expended in work (Lawrence and Stibbards, 1990).

RESULTS

Experiment One

The results obtained with the Shetland ponies are presented in Table 1. The mean energy cost of standing was not significantly different during each of the different speed treatments. The overall mean standing value was 1.37 W/kg live weight (s.e. 0.02).

The total energy used when walking (W/kg live weight), as expected, increased significantly with increasing speed, although the difference between energy expenditure at speeds of 0.63 m/s and 0.87 m/s was not significant (Table 1). The relationship between the total energy used for walking (Y W/kg) and speed (X, m/s) was as follows:

$$Y = 1.32 + 1.09\,X \quad (r^2 = 0.7)$$

When extrapolated back to zero speed, the equation predicted a value of 1.32 W/kg for standing (Figure 1). This compares with a measured value of 1.37 W/kg.

The net energy cost of walking (J/m walked/kg live weight) above standing did not show any significant change as speed increased, mean value = 1.02 J/m/kg (s.e. 0.01).

Table 1. **Mean (s.e.) energy costs of standing and of walking at four different speeds on a treadmill by four Shetland ponies (n=24). Results are expressed per kg liveweight (Experiment One)**

					Energy costs of walking		
	Energy used for standing (W/kg)		Speed (m/s)		Total cost (W/kg)		Unit cost s.e. (J/m/kg)
Expt.	mean	s.e.	mean	s.e.	mean	s.e.	mean
	.32	0.03	0.35	0.004	1.67^a	0.03	1.04
2	1.43	0.04	0.63	0.003	2.08^b	0.05	1.05
3	1.35	0.06	0.87	0.006	2.16^b	0.05	0.96
4	.37	0.04	1.13	0.007	2.57^c	0.04	1.03

^{a,b,c} Within columns means followed by different superscripts are significantly different (P<0.05)

Experiment Two

The average energy used for standing by the Shetland ponies in this experiment was 1.93 W/kg live weight (s.e. 0.085). The energy used for standing was significantly (P<0.05) different between ponies (Table 2). The average energy cost of walking was 1.17 J/m/kg live weight (s.e. 0.05). Differences in the energy cost of walking between ponies were not significant in four of the animals, the exception was the pony Silver, which always had a significantly (P<0.05) higher energy cost of walking than the other ponies (Table 2).

Between ponies, there was no significant difference in the energy costs of pulling loads. Differences were seen, however, in the energy costs per kg load pulled at the different load treatments (Table 3). The average energy used for pulling was 31.2 J/m/kg pulled. Energy costs of pulling per kg load were significantly higher when ponies pulled the lightest load (5 kg df/100 kg live weight) than at the two heavier loads. The ponies were most efficient at pulling 10 kg df/100 kg live weight although differences in efficiency between loads were small. Differences in efficiency between animals were not significant.

The relationship between total energy used when pulling and load pulled was determined mathematically and is given in Figure 2.

DISCUSSION

The energy used for standing measured for Shetland ponies in the present study (1.37 W/kg live weight, Experiment One, 1.93 W/kg live weight, Experiment Two) were higher than the values of 1.05 and 1.14 W/kg estimated by Pagan and Hintz (1986a) for their smallest animals (125 and 206 kg). Their animals were confined in metabolism crates during observations while the ponies in the present study were standing alert on the treadmill ready to start, or having finished walking or working. This probably also explained the differences observed in the present study.

Table 2 **Mean (s.e.) energy costs of standing and of walking on a treadmill by five Shetland ponies (n=13) in Experiment Two. Results are expressed per kg liveweight**

	Energy used		Energy costs of walking			
	For standing (W/kg)		Total cost (W/kg)		Unit cost (J/m/kg)	
Animal	mean	s.e.	mean	s.e.	mean	s.e.
Silver	1.91^{a}	0.11	3.38	0.08	1.46^{a}	0.07
Pawnee	2.16^{b}	0.10	3.32	0.07	1.15^{b}	0.05
Deil	1.49^{c}	0.07	2.66	0.04	1.17^{b}	0.03
Comanche	$.86^{a}$	0.06	2.86	0.04	1.00^{b}	0.03
Apache	2.28^{b}	0.08	3.33	0.07	1.05^{b}	0.05

a,b,c Within columns means followed by different superscripts are significantly different ($P<0.05$)

Table 3. **Energy costs of pulling loads singly on a treadmill and the efficiency with which five Shetland ponies used energy for work at three different loads (Experiment Two)**

Load kgdf/100 kg liveweight	n	Unit energy cost of pulling (J/m/kg load (pulled) mean	s.e.	Efficiency of working workdone/ energy used (%)	s.e.
5	25	33.12[a]	0.70	33	0.7
10	20	29.11[b]	0.84	34	0.9
15	20	31.36[b]	0.74	30	0.5

(Experiment One) between the measured energy cost of standing (1.37 W/kg) and the slightly lower value obtained by extrapolating walking values at different speeds back to zero (1.32 W/kg).

The net energy cost of walking in the four ponies used in both experiments was consistent (1.02 J/m/kg, Experiment One, and 1.09 J/m/kg, Experiment Two). The fifth pony showed a marginally higher energy cost of walking than the others (1.46 J/m/kg).

Experiment One showed that the net energy costs of walking, above that used for standing by the ponies did not change as the speed of walking increased. This observation was also found in cattle, buffalo (Lawrence and Stibbards, 1990) and donkeys (Dijkman, 1992), where, within the comfortable range of walking speeds, there was no significant change in energy cost of walking with speed (J/m/kg). The fastest speed used in Experiment One (1.13 m/s) was close to the measured walking speed of the ponies in the field (about 1.0 m/s).

A comparison of the energy costs of walking from treadmill studies between equids indicates that donkeys have the lowest energy costs (0.97 J/m/kg, Dijkman, 1992), followed by Shetland ponies (1.06 J/m/kg, present study) and then horses (1.6 J/m/kg, Hoffmann, *et al.*, 1967). Cattle and buffalo seem to expend more energy in walking (J/m/kg) than equids (1.91 J/m/kg, Lawrence and Stibbards, 1990; 2.1 J/m/kg, Ribeiro, Brockway and Webster, 1977). These differences may at least partly be accounted for by anatomical differences between the species.

Figure 1. Relationship between speed of walking and total energy used in ponies weighing 160 to 230 kg

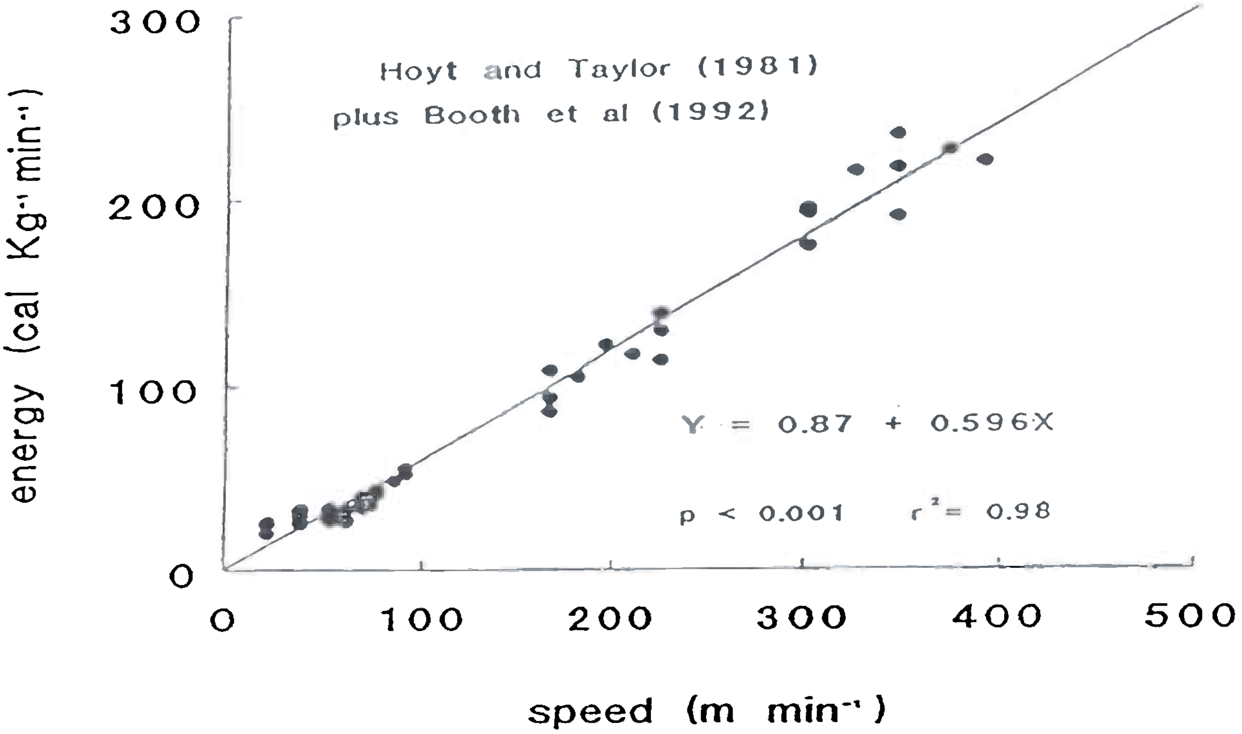
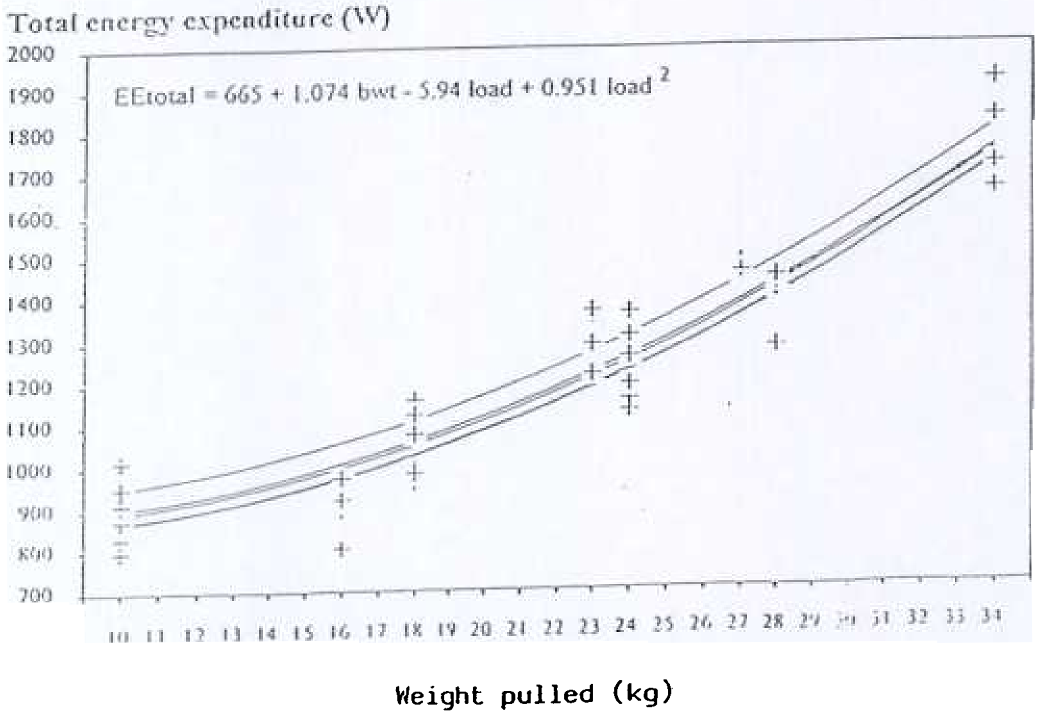


Figure 2. Relationship between weight pulled and total energy used in ponies weighing 160 to 230 kg



Unlike the energy used for walking, the energy used for pulling by the different species seems to be remarkably consistent. For single animals working, the results showed that the efficiency with which ponies use energy for work (0.33, 0.34, and 0.30, Experiment Two) is within the range found for other draught animals - cattle, 0.30, (Lawrence and Stibbards, 1990), large horses, 0.35 (Brody, 1945), buffalo, 0.36 (Lawrence and Stibbards, 1990) and donkeys, 0.37 (Dijkman, 1992).

Within the range of draught forces investigated, load did have a measurable effect on the efficiency with which the ponies used energy for work. A draught force of 10 kg df/100 kg live weight seemed in the present experiment to represent the work load at which energy was used most efficiently by the ponies for pulling, when compared with forces of 5 and 15 kg df/100 kg live weight. This is consistent with the generally held view when matching animals to implements that healthy well-fed light horses can exert a force equivalent to 10 to 12 per cent of their live continuously over a working day (FAO, 1972).

Pagan and Hintz (1986b) have produced an equation for predicting the additional energy requirements for exercise above energy needed for maintenance:

$Y(\text{cal/kg/min}) = e^{(3.02 + 0.0065X)}$

where X = speed (m/min)

Inserting a value of 1.13 m/s in the above equation, i.e. the speed at which the ponies in Experiment One walked, predicted a net energy requirement of 2.21 W/kg. This was less than the actual value of 2.57 W/kg obtained in Experiment One. Pagan and Hintz's (1986b) equation above was derived using four horses weighing between 433 and 520 kg, working submaximally at speeds from 0.67 to 6.5 m/s. The present study suggests that this formula, developed using saddle horses (Pagan and Hintz, 1986a,b), may underestimate energy requirements for exercise in ponies of low live weight and therefore be inappropriate.

To investigate the relationship between the total net energy required for exercise and speed in small equids, data from the ponies in experiment One (110-230 kg) and from similar studies of ponies with live weights of less than 170 kg (Hoyt and Taylor, 1981) was pooled and a regression line plotted (Figure One). The following equation described the relationship between total net energy cost, Y (cal/kg/min) and speed, X (m/min):

$Y = 0.87 + 0.596X \; (r^2 = 0.98)$

PART TWO - Field studies

INTRODUCTION

In laboratory studies work output and the conditions under which the work is done can be regulated and repeated using treadmills, loading devices and controlled environment conditions. This is useful when comparisons between animals or species are required or when effects of particular treatments are being investigated such as the effects of speed or draught force on energy expenditure. However the environment can have a considerable influence on the animals energy needs. The terrain in particular affects the energy costs of walking. To study energy requirements in the field a portable system of oxygen analysis is required. Lawrence and Dijkman (Lawrence, Pearson and Dijkman, 1991) developed a portable breath-by-breath oxygen analyser for use with animals. This was based on the OXYLOG (P.K. Morgan Ltd, Kent, UK), originally developed for use with human beings (Humphrey and Wolff, 1977). This has enabled oxygen consumption to be measured directly in working animals in the field. In the present studies the energy used by ponies to move over different terrain has been determined in the UK (Experiment Three). In addition the energy costs of carrying and pulling loads by working donkeys have been studied in Tunisia and Niger, respectively (Experiments Four and Five). The modified OXYLOG has been used in all cases. The preliminary results of all three studies are reported here.

MATERIAL AND METHODS

Animals, Management and Experimental Routine

Experiment Three - The effects of ground surface condition on the energy costs of walking by ponies

The experimental studies were carried out at the University of Edinburgh. Five male Shetland ponies (150-234 kg) were trained to wear the airtight face mask and carry the portable breath-by-breath oxygen analyser. Animals walked individually for about 20 minutes in a circle (diameter approx 8 m) on one of two different surfaces, concrete or mud. The mud consisted of the concrete surface covered in wet clay/loam soil to a depth of 120 mm. The animals travelled an average distance of 1.2 km. Prior to the start of and at the end of each walking period the standing metabolic rate of the animal wearing the Oxylog was obtained in a 20 minute measurement period. Two ponies were monitored each morning and one in the afternoon. Ponies only worked once in a day. Measurements were replicated four times in each pony for each treatment.

Experiment Four - The effect of load carrying on energy expenditure of donkeys in Tunisia

Four entire male donkeys (150-183 kg live weight) were used in the experiment at the Ecole Superieure d'Agriculture in Mateur, Tunisia in October 1993. Animals received a daily diet consisting of 1 kg of crushed barley and *ad libitum* wheat straw. The donkeys were divided into two groups, which worked for two weeks followed by two weeks rest, or vice versa, during a four week experimental period. During the 5 day/week work the donkeys wore the locally used pack saddle and carried a load equal to 40% of their body weight, whilst walking on a 400 m, slightly undulating track. Total distance walked was 10 km/day, divided into a 6 km walk in the morning and a 4 km walk during the afternoon session.

Donkeys undergoing the working treatment alternately wore the modified Oxylog equipment during the morning or afternoon work session. Prior to the start of, and at the end of the working period the standing metabolic rate of the animal wearing the Oxylog was obtained in a 20 minute measurement period.

Experiment Five - Work potential and energy requirements of donkeys in semi-arid areas

Studies of work output and energy metabolism of donkeys were carried out at the ICRISAT Sahelian Centre, Sadore, Niger in June, July and August 1993. Average daily temperature varied from 25-27°C in the early morning to 30-37°C in the mid afternoon, with violent rain storms usually of short duration approximately every third day.

Six female donkeys, aged 3 to 10 years, mean live weight 134 kg (s.d. 15) were housed individually in stalls. Each animal received a daily diet of *ad libitum* millet stover, chopped to 0.3 m lengths, and 600 g of concentrate (composition 600 g/kg wheat bran, 350 g/kg peanut meal and 50 g/kg mineral mix). Water was available ad libitum in the stalls.

The energy cost of walking at a naturally determined speed on level dry sandy/gravel tracks was determined in mid to late afternoon, using the Oxylog equipment. The donkeys walked unloaded for 30 minutes during which they covered an average distance of 2.1 km. In a separate study the donkeys worked continuously in pairs for two hours in the afternoon. Work consisted of pulling a loaded sledge round a level sandy/gravel track at an average draught force of 10 kgdf/100 kg live weight. Oxygen consumption of one donkey in each team was determined in turn during work.

Measurements

Measurements of speed (m/s), minute VO_2 or total oxygen consumption and body weight (kg) allowed calculation of the total energy used while standing and walking (W/kg) and the net energy costs of walking (J/kg/m). Where appropriate in the experiments load carried was measured and total work done, distance travelled and time spent working, using an ergometer (Lawrence and Pearson, 1985). These, with oxygen consumption enabled the unit energy costs of pulling and carrying to be determined. Energy expenditure was determined from oxygen consumption according to Brouwer (1965).

Table 4. Mean (s.e.) speed and energy costs of standing and of walking on two different surfaces outdoors by five Shetland ponies in Experiment Three. Results are expressed per kg liveweight

	Concrete (n=24)				Mud (n=23)			
	Standing		Walking		Standing		Walking	
Speed	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
(m/s)	0		.18	0.008	0		0.99	0.017
Total energy used (W/kg)	1.47^{a}	0.08	4.48^{b}	0.17	1.30^{a}	0.05	7.17^{c}	0.29
Unit energy cost walking (J/m/kg)			2.52^{a}	0.07			5.81^{b}	0.23

^{a,b,c} Means within rows followed by different superscripts are significantly different (P<0.05)

RESULTS

Experiment Three

The energy used by Shetland ponies in UK while standing and walking on the different surfaces is given in Table 4. The average energy used for standing by the ponies in this experiment was 1.38 W/kg live weight. All ponies used significantly (P<0.001) more energy to walk in mud than on the concrete surface.

Experiment Four

The total energy used when standing, walking unloaded and when carrying a load is given in Table 5. The average energy used for standing by the donkeys in this experiment in Tunisia was 2.72 W/kg live weight. The average energy cost of walking unloaded was 1.37 J/m/kg live weight. The unit energy costs of walking and carrying (J/m/kg live weight and kg carried, respectively) for each donkey are given in Table 6.

Experiment Five

The preliminary results of this work, which was partly funded by STD-2 money, are reported here. The average energy used for standing by the donkeys in this experiment in Niger was 1.40 W/kg live weight. The average energy cost of walking was 1.43 J/m/kg live weight (Table 7).

The amount of work that teams of two donkeys were capable of doing in a two hour period when pulling loads with a draught force equivalent to 10 wkgdf/100 kg live weight is given in Table 8 for three teams of donkeys. The rate of energy expenditure when working is also given. In this part of the study, the energy used for walking unloaded was not determined so unit energy costs of pulling (J/m/kg pulled) were not calculated. However to estimate the efficiency with which each donkey in a team appeared to use energy for work the rate of energy used during work in this+ study and that used while standing and while walking in the walking study were compared. The work done by each team was assumed to be attributable equally to each animal in the team. The average estimated efficiency of doing work using these figures from the three teams was proportionately 0.21.

Table 5. Mean (s.e.) energy used for standing, walking, unloaded and walking loaded (40 kg load/100 kg liveweight) on undulating sandy tracks by three donkeys in Experiment Four (n=9). Results are experienced per kg liveweight

			Walking			
			Unloaded		Loaded	
Animal	Energy used for standing (W/kg) mean	s.e.	Speed (m/s)	Energy used (W/kg) mean	Speed (m/s)	Energy used W/kg
	3.04	0.09	1.19	4.64	1.17	5.72
2	2.59	0.15	0.99	3.98	1.08	5.05
3	2.53	0.11	1.13	4.07	1.16	5.03

Table 6. **Mean (s.e.) unit energy costs of walking and of carrying loads over undulating sandy tracks by three donkeys in Experiment Four (n=9)**

	Unit energy cost of	
Animal	Walking (J/m/kg liveweight) mean	Carrying loads (J/m/kg load carried) mean
	1.35	2.50
2	1.40	2.47
3	1.36	2.06

Table 7. **Mean (s.e.) energy costs of standing and walking over sandy tracks by five female donkeys in Experiment Five. Results are expressed per kg liveweight (n=3)**

	Energy used for				Energy costs of walking		
Animal	Standing (W/kg) mean	s.e.	Speed (m/s) mean	s.e.	Total costs (W/kg) mean	s.e.	Unit costs J/m/kg mean
31	1.73	0.28	1.27	0.05	3.43	0.19	1.34
57	1.18	0.15	1.32	0.09	3.66	0.20	1.87
41	1.21		1.29	0.01	3.33	0.22	1.64
84	1.18	0.16	1.30	0.03	2.93	0.19	1.35
0	1.70		1.23	0.03	2.83	0.38	0.93

Table 8. **Work performance by three pairs of donkeys pulling loads over sandy tracks for a two hour period and rate of energy expenditure by one donkey in each team in Experiment Five**

Team	Average draught force (N)	Distance travelled (km)	Work done (kJ)	Percentage of time spent working (%)	Power (W)	Average rate of energy used (W/kg)
1	318	6.54	2083	87.3	331	9.19
2	312	6.59	2055	8.53	335	8.99
3	255	6.35	1617	81.7	275	9.69

DISCUSSION

A comparison of these results from the field studies (Experiments Three, Four and Five) and the observations in the laboratory (Experiments One and Two) show that situation can have an effect on energy expenditure (Table 9). Energy used for standing was highest per kg live weight in the Tunisian donkeys. These animals had least time to become accustomed to the experimental procedures of all the animals used in the experiments, due to the short time available to carry out the study. Apprehension may well have accounted for the higher standing values in these animals, since there was a downward trend in standing energy values in all the donkeys during the course of the study in Tunisia. Clearly environmental surroundings, type and temperament of equid will influence the resting or basal values obtained.

Dijkman (1993) reported lower values for the energy costs of walking on hard level ground by cattle in the field than on treadmills, and suggested that this may have been due to the animals being able to determine their own preferred speed of walking. This was not observed in the present experiment, although the 'hard' surfaces in the field studies were covered in sandy-gravel and so probably did not represent a direct comparison.

The type of surface that the ponies and donkeys walked on, as might be expected, had the greatest effect on energy requirements during exercise.

Ponies increased the energy they used for walking by over two-fold when they walked in a depth of 120 mm of mud (5.81 J/m/kg), compared with energy used for walking on concrete (2.52 J/m/kg). Lawrence (1987) observed similar changes in the magnitude of energy used for walking when cattle and buffaloes walked in mud,

Table 9. **Summary of experimental observations of the energy costs of standing, walking, pulling and carrying loads in the five experiments (average values)**

Expt.		2	3	4	5
Location	UK	UK	UK	Tunisia	Niger
Site	Laboratory treadmill	Laboratory treadmill	Concrete/ mud	Sandy/ gravel track	Sandy/ gravel track
Species	Pony	Pony	Pony	Donkey	Donkey
Average energy used for standing (W/kg liveweight)	.37	.93	.38	2.72	1.40
Average energy cost of walking J/m/kg	.02	.09	2.52(concrete) 5.81(mud)	.37	.43
Average energy cost of pulling J/m/kg pulled		31.2			
Average energy cost of carrying J/m/kg carried				2.34	

compared with when they walked on concrete. He found that the energy cost ofwalking was 90 per cent higher on average when the animals walked in a 300 mm depth of mud than on concrete (3.34 J/m/kg vs. 1.76 J/m/kg; Lawrence, 1987). Dijkman (1993) found an even greater increase in energy costs of walking when cattle walked in waterlogged soil in Nigeria. Walking on unploughed firm 'upland' cattle used an average of 1.47 J/m/kg and on the same ploughed land, 2.87 J/m/kg. However on wet 'Fadama' land, into which their feet sank <250 mm, the cattle used an average of 3.3 J/m/kg and on the same land ploughed used 8.58 J/m/kg, almost an eight-fold increase over energy used on hard dry land (Dijkman, 1993). The donkeys in the present study walking over firm sandy/gravel tracks used more energy for walking (1.35 J/m/kg) than those observed in treadmill studies (0.97 J/m/kg) by Dijkman (1992). Interestingly in the present study, energy costs for ponies walking in a circle seemed to be considerably higher than those recorded for both ponies and donkeys walking on firm surfaces in straight lines (Table 9). Slope will also have an effect on the energy costs of walking. For example the Shetland ponies from Experiment Two used 5.90 J/m/kg walking up a 2.2 % gradient on grass and 7.30 J/m/kg walking up a 10% uphill grass gradient (Booth, personal communication).

Clearly in determining the energy requirements of working ponies and donkeys it is necessary to consider the terrain over which the animals are working and adjust the energy needs for walking accordingly.

When studying the energy used in pulling loads the efficiency with which single animals use energy for work seemed to be relatively consistent between species (0.30 0.37, see above) however when the calculations are done for paired animals there would appear to be loss of efficiency (0.21). Some loss of efficiency would be expected since two animals, even experienced draught animals, will often pull against each other when working in a team, however the magnitude of such losses warrants further investigation. The observations reported here were estimates based on extrapolation from separate studies, although they did use the same animals in the same area, Niger and therefore cannot be relied on.

The extra energy used for carrying 40 kg/100kg live weight by the donkeys in Tunisia in the present study (2.34 J/m/kg carried) was more that seen in laboratory studies of donkeys carrying lighter loads on the level (1.1 J/m/kg carried, Dijkman, 1992) but similar to observations of donkeys carrying loads up and down gradual slopes or on undulating ground (2.7-3.3 J/m/kg, Yousef and Dill, 1969; Yousef *et al.*, 1972; Dijkman, 1992). In all these studies time was spent ensuring loads were balanced on the donkeys. An unbalanced load adds considerably to the energy costs of carrying, two to three fold increases in the energy costs of carrying were observed in the present Tunisian study when loads were purposely unbalanced (Dijkman, personal communication).

CONCLUSIONS

Values obtained for the energy costs for the various activities associated with work in ponies and donkeys obtained in the present study are summarised in Table 9.

A number of conclusions can be made which have implications for feeding and managing working equids:

As with other species studied, the energy costs of walking depend on the type of ground surface over which the animal is walking. At least two-fold increases in energy costs of walking can be expected when the ground is muddy. This needs to be considered when estimating the energy needed for work.

Within normal walking speeds, speed seems to have little effect on the net energy used for walking. Therefore, provided the surface type, the distance travelled and the live weight of the animal are known it is possible to estimate the extra energy needed for walking.

Net energy costs of pulling seem less affected by surface over which the work is done than by harnessing. Therefore provided the draught force exerted, distance travelled and live weight are known extra energy needs for work can be calculated.

Single ponies seem to be more efficiently energetically, when working at draught forces of 10 kgdf/100 kg live weight than at 5 or 15 kgdf/100 kg live weight.

If the animal is working as a pair then some allowance for loss of efficiency in which energy is used for work needs to be made. Best estimates to date for pairs of donkeys in breast-plate harness were efficiencies of 0.21, compared to efficiencies of 0.30-0.37 for single ponies and donkeys.

Net energy costs of carrying loads by donkeys seem to be dependent on the balance of the load on the animal. This changes with changes in the slope of the ground over which the load is carried and may account for the differences in energy costs of carrying seen in this and other experiments on donkeys.

Energy costs of walking are lower in equids than in draught ruminants. Therefore for light tasks, not requiring high draught forces, theoretically donkeys and light horses can offer a more efficient alternative to ruminants in terms of the use of animal energy for work. Obviously other factors, such as provision of net energy from feedstuffs, which is influenced by type and quality of feed available as well as type of animal also come into this argument.

Data collected for large horses may not always be appropriate for smaller horses and donkeys.

Table 10 gives estimates of the energy requirements for equids carrying out some common work activities based on the experiments above and information from the literature and practical observation (R.A. Pearson and E. Nengomasha unpublished) of common working practices in some of the rural areas of the world where equids are used for work.

Future studies on this topic should include investigation of the efficiency with which animals use energy for work when working in teams of two and four, the energy used for working up and down gradients, and the energy used for work at different speeds, particularly at trot. Equids carting light loads often travel in trot as well as walk, unlike ruminants. More information is also needed on the effects of the environment on energy requirements of working animals. This would include effects of training, different ground conditions and climate.

Table 10. **Estimates of the additional net energy needed for work by each pony or donkeys carrying out typical rural tasks based on the energy costs of walking, pulling and carrying from the present study**

Type of animal	Liveweight	Task	Duration of work hrs	Speed (m/s)	Distance travelled (km)	Load or draught force (N)	Additional net energy by each animal (above maintenance) (MJ)
Donkey	105	pack on sand/gravel	8	1.4	40.0	40 kg	9.50
Pony	200	carting on tarmac	4	.2	17.3	180 N	12.83
Donkey	140	weeding	4	0.90	13.0	260 N	16.05
Pony	250	carting in pairs on gravel tracks	6	.4	30.2	250 N	21.45

REFERENCES

Brody, S. (1945). Bioenergetics and growth, Reinhold, New York.

Brouwer, E. (1965). Report of the sub-committee on constants and factors. *Proceedings of the Third Symposium on Energy Metabolism, Troon* (ed. K.L. Blaxter), pp. 441-443. Academic Press, London.

Dijkman, J.T. (1992). A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads. *Animal Production*, **54**, 153-156.

Dijkman, J.T. (1993). The measurement of draught ruminant energy expenditure in the field. PhD Thesis, Centre for Tropical Veterinary Medicine, University of Edinburgh.

Food and Agriculture Organisation (1972). Manual on the employment of Draught Animals in Agriculture, FAO, Rome.

Hoffman, L., Klippel, W. and Schiemann, R. (1967). Untersuchungen uber den Energieumsatz beim pferd unter besonderer Berucksichtigung der Horizontal bewegung. *Archives Tierernaehr*, 17, 441-452.

Hoyt, D.F. and Taylor, C.R. (1981). Gait and the energetics of locomotion in horses. *Nature*, **292**, 16 July.

Humphrey S.J. and Wolf, H.S. (1977). The Oxylog. *Journal of Physiology, London*, **267**, 12 Abst.

Lawrence, P.R. (1989). Facilities for measuring gaseous exchange of large ruminants when working and resting. In: *Draught Animals in Rural Development* (eds. D. Hoffmann, J. Nari and R.J. Petheram). ACIAR Proceedings Series No. 27, pp. 330 Abst. ACIAR, Canberra.

Lawrence, P.R. (1987). Mud, mud, glorious mud. *Draught Animal News*, **7**, 1-2.

Lawrence, P.R. and Pearson, R.A. (1985). Factors affecting the measurements of draught force, work output and power of oxen. *Journal of Agricultural Science, Cambridge*, **105**, 703-714.

Lawrence, P.R. and Stibbards, R.J. (1990). The energy cost of walking, carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffalo. *Animal Production*, **50**, 29-39.

Lawrence, P.R., Pearson, R.A. and Dijkman, J.T. (1991). Techniques for measuring whole body energy expenditure of working animals — A critical review. In: *Isotopes and Related Techniques in Animal Production and Health.* Proceedings of a Symposium, Vienna, IAEA/FAO. pp. 211-232, IAEA, Vienna.

Pagan, J.D., Hintz, H.F. (1986a). Equine energetics. I. Relationship between body weight and energy requirements in horses. *Journal of Animal Science*, **63**, 815-821.

Pagan, J.D., Hintz, H.F. (1986b). Equine energetics. II. Energy expenditure in horses during submaximal exercise. *Journal of Animal Science*, **63**, 822-830.

Riberio, J.M de C.R., Brockway, J.M. and Webster, A.J.F. (1977). A note on the energy costs of walking in cattle. *Animal Production*, **25**, 107-110.

Richards, J.I. and Lawrence, P.R. (1984). The estimation of energy expenditure from heart rate measurements in working oxen and buffalo. *Journal of Agricultural Science*, **102**, 711-717.

Yousef, M.J. and Dill, D.B. (1969). Energy expenditure in desert walks: man and burro, *Equus asinus*. *Journal of Applied Physiology*, **27**, 681-683.

Yousef, M.K., Dill, D.B. and Freeland, D.V. (1972). Energetic cost of grade walking in man and burro, *Equus asinus*: desert and mountain. *Journal of Applied Physiology*, **33**, 337-340.

ACKNOWLEDGMENTS

The following are gratefully acknowledged for their contributions to this study:

The British Overseas Development Administration and the British Veterinary Association Animal Welfare Foundation (BVA) for additional financial support.

The donkey study in Niger was carried out by Pamela Mueller, a graduate student of Cornell University, in collaboration with ILCA and CTVM who provided facilities and equipment, and ICRISAT, who provided land and donkeys.

The study of the energy costs of walking in ponies was carried out by Mary Booth a BVA postgraduate student at the University of Edinburgh.

David Smith, from CTVM and Annet Nahuis, as part of her MSc studies at CTVM, investigated the energy needs for work by ponies.

Jeroen Dijkman, from CTVM was responsible for the work in Tunisia on donkeys. The Ecole Superieure d'Agriculture in Mateur provided animals and facilities there.

The support and assistance of Bob Archibald, Iain Campbell, Derek Cuddeford, Will Goad and Paul Wright was much appreciated in various aspects of the work.

PUBLICATIONS

PUBLISHED:

Booth, M.E., Pearson, R.A. and Cuddeford, D. (1993) The effect of speed of walking on the energy cost of walking in ponies. 43rd Annual Meeting of the European Association for Animal Production, Madrid, September 1992 vol 2: 542-543.

Durrans, L (1991). An investigation of digestibility and gastro-intestinal transit time of diets of varying fibre contents by donkeys (*Equus asinus*) and ponies (*Equus caballus*). Thesis in partial fulfilment of Bsc degree in Agricultural Science, University of Edinburgh. April 1991.

Nahuis, A. (1993). Energy cost of walking and pulling loads at different draught forces by Shetland ponies. Thesis in partial fulfilment of MSc degree in Tropical Animal Production and Health, University of Edinburgh. September 1993.

Pearson, R.A., Cuddeford, D., Archibald R.F. and Muirhead, R.H. (1992). Digestibility of diets containing different proportions of alfalfa and oat straw in Thoroughbreds, Shetland ponies, Highland ponies and donkeys. *Proceedings of the First European Conference on Equine Nutrition. Pferdeheilkunde Sondersgabe, 1992 153-157.*

IN PREPARATION:

Smith, D.G., Nahuis, A., Pearson, R.A. and Archibald, R.F. 1994. A comparison of the energy cost of work in donkeys, ponies and cattle. for Second International Colloquium on Working Equines, Rabat, Morocco, April 1994.

Dijkman, J.T. 1994. The effect of carrying loads on feed intake, digestibility and energy expenditure of donkeys in Tunisia.

Mueller, P. and Fall, A. 1994. A comparison of donkeys and draught cattle working in Niger: intake, digestibility, energy expenditure and physiological changes associated with work at high temperatures.

Estimation of the liveweight and body condition of working donkeys in Morocco

R. A. Pearson, M. Ouassat

Veterinary Record (1996) 138, 229-233

The age, sex, liveweight and body measurements (heart girth, umbilical girth, height, length from elbow to tuber ischii and circumference of the foreleg cannon bone) of 516 donkeys used to transport goods in Morocco were recorded. There were few donkeys over 12 years of age. For adult donkeys weighing from 74 to 252 kg, the best equation with only one variable for predicting liveweight was: liveweight (kg) = heart girth (cm)$^{2.65}$/2188. The inclusion of two variables improved the prediction marginally, but the addition of further variables gave little further improvement. The best prediction equation for adult donkeys was: liveweight (kg) = (heart girth [cm]$^{2.12}$ x length [cm]$^{0.688}$)/380. For donkeys under three years of age, weighing from 52 to 128 kg, the best prediction equation was: liveweight (kg) = (umbilical girth [cm]$^{1.41}$ x length [cm]$^{1.09}$)/1000. Other liveweight prediction equations for donkeys and horses were tested on the data and tended to overestimate the weight of these working donkeys. A subjective method for assessing the body condition of the donkeys was developed, using a scale from 1 (emaciated) to 9 (obese).

A RELIABLE method for assessing the liveweight of donkeys would be useful for several reasons: to judge the correct dosages of drugs when treating them, to assess the adequacy of their diet and their well-being, to assess the effects of treatment or changes in diet, and to help in making sound recommendations for the loads to be carried by donkeys. Unfortunately, weighing machines are seldom available where donkeys are kept for work. The estimation of liveweight, making use of simple techniques such as body measurements, that could be used in markets or on farms, could provide an alternative to direct weighing.

For over a century, linear body measurements have been used in mathematical equations to estimate the liveweight of cattle (Brody 1945, Johansson and Hildeman 1954, Davis and others 1961). A linear relationship is normally used (Johnson 1940, Wanderstock and Salisbury 1946, Burt 1957). The allometric equation: liveweight = a x heart girth^b, where a and b are constants for a particular breed, corresponded best with the regression of liveweight on heart girth (Johansson and Hildeman 1954); the value of b approaches 3 because bodyweight varies approximately with the cube of the heart girth. The error involved in the estimation of liveweight from heart girth may be reduced if the heart girth is combined with other linear body measurements (Johnson 1940, Burt 1957).

In estimating the liveweight of horses, researchers have used length in addition to the heart or umbilical girth (Milner and Hewitt 1969, Carroll and Huntington 1988, Jones and others 1989). These measurements appear to give reasonably accurate predictions of liveweight for horses and ponies.

Neale (1990) and Eley and French (1993) each developed a prediction equation for donkeys, because they found that the methods used to estimate the liveweight of horses were inappropriate. Neale (1990) used heart girth and length as body measurements and Eley and French (1993) used girth and height. Neale measured 69 donkeys and Eley and French measured 217 adult and 26 young donkeys kept at a donkey sanctuary in Britain. An equation derived from measurements of these largely sedentary donkeys in Britain may not be appropriate for use with the working donkeys found in the semi-arid and mountainous areas of the world. The purpose of the present study was to obtain sufficient data on the liveweight and body measurements of working donkeys to derive an equation for estimating their liveweight and to compare the actual and estimated liveweights with those predicted from other equations used for horses and donkeys.

A large number of donkeys was examined over a relatively short time and, the opportunity was therefore taken to develop and test a method of body condition scoring for donkeys and to examine the age structure of the working donkey population. Carroll and Huntington (1988) found that body condition score and height gave almost as accurate an estimate of the liveweight of thoroughbred horses as girth and length measurements. However, in the present study it was decided to restrict the analyses to the objective measurements and not to use the subjective measurement of body condition in the predictive equations.

Materials and methods

Four hundred donkeys in the souks around Rabat and Settat were measured in May 1993, and 116 donkeys from Khemisset and Tifelt were measured in June 1993. These donkeys were used by local farmers to bring their goods to the weekly markets. They were weighed on a portable electronic weight scale (Ruddweigh).

The following body measurements were taken: the heart girth (the circumference measured from the caudal edge of the withers around the girth behind the elbow), the umbilical girth (the body circumference around the umbilicus), the height (measured with a measuring stick at the highest point of the withers with each donkey standing squarely on level ground with its head in a normal position), the length from the olecranon process of the elbow to the tuber ischii (taken with a measuring stick) and the circumference of the foreleg cannon bone measured around its narrowest part. The age (from an assessment of the incisors), sex and body condition of the donkeys were also recorded. Jones and others (1989) reported that the measurement of body length from the tuber ischii to the elbow was easier and more repeatable than the measurement from the tuber ischii to the point of the shoulder. The former measurement of length was therefore used. Carroll and Huntington (1988) measured heart girth after a respiratory expiration. Neale (1990) reported little difference between the measurements of girth taken during peak inspiration and expiration. As a result of these observations, and of the practicalities of measurements in the field, the time during the respiratory cycle at which the measurements of girth were taken was not standardised. A measuring stick, with a right angle bend approximately 20 cm from one end, greatly facilitated the measurement of length. The short piece at right angles to the main stick was placed against the point of the buttock (the tuber ischii) and the stick (graduated in length) was laid alongside the animal to the elbow, where its length was then read. In preliminary tests, measurements on each side of the animal showed little variation between the two sides. The liveweight was recorded to the nearest kilogram, the length, girth and height to the nearest centimetre and the circumference of the cannon to the nearest 50 mm.

The animals were marked with an indelible pen when they had been measured to prevent them being recorded a second time. A standard weight was used to check the weigh-scale each time it was set up and at regular intervals throughout each series of weighings. Fifty donkeys were weighed twice, having stepped on and off the scale, to check the repeatability of the measurement; it

R. A. Pearson, BSc, PhD, Centre for Tropical Veterinary Medicine, University of Edinburgh, Easter Bush, Roslin, Midlothian EH25 9RG
M. Ouassat, DVM, PhD, Institut Agronomique et Vétérinaire, Hassan II, Rabat, Morocco

TABLE 1: Guide to the body condition scoring of donkeys

Score	Description
Very thin (emaciated)	Animal markedly emaciated; condemned; bone structure easily seen over body; little muscle present; animal weak; lethargic
2 Thin	Animal emaciated; individual spinous processes, ribs, tuber coxae, tuber ischii and scapular spine all prominent, sharply defined; some muscle development; neck thin; prominent withers; shoulders sharply angular
3 Less thin	Vertebral column prominent and individual spinous processes can be felt (palpated); little fat, but superspinous musculature over spinous processes apparent. Ribs, tuber ischii and tuber coxae prominent; loin area and rump concave; little muscle or fat covering over withers and shoulders
4 Less than moderate	Vertebral column visible; tuber ischii palpable but not visible, tuber coxae rounded but visible; rump flat rather than concave; ribs palpable but not obvious; withers, shoulders, neck with some muscle and fat cover; scapulare less clearly defined
5 Moderate	Superspinous muscles developed and readily apparent; can palpate vertebral column; tuber coxae rounded; rump rounded, convex; tuber ischii not visible; some fat palpable in pectoral region and at base of neck; can palpate ribs, but not visible
6 More than moderate	Cannot palpate spinous processes easily; back becoming flat, well covered; rump convex and well muscled; some fat palpable on neck, base of neck and pectoral region; neck filled into shoulder, tuber coxae just visible
7 Less fat	Back flat, cannot palpate spinous processes; tuber coxae just visible; fat on neck and pectoral region beginning to expand over ribs; flank filling; neck thickening
Fat	Animal appears well covered with body rounded with fat and bones not discernible; flanks filled; broad back
9 Very fat (obese)	Bones buried in fat; back broad or flat, in some cases crease down back; large accumulations of fat on neck, over pectoral area and ribs; flank filled with fat

1 to 3 frame obvious; 4 to 6 frame and covering balanced, 7 to 9 frame not as obvious as covering

Individual donkeys can deposit their body fat in different areas of the body, so the individual neck, shoulders, ribs, rump and flank condition should be assessed and combined to give an overall condition score

was found to be virtually 100 per cent, because only two donkeys gave values differing by up to 2 kg. The donkeys were selected for weighing in the markets on a completely random basis. Little difficulty was experienced in getting the donkeys to stand on the weigh-platform.

Body condition

A subjective assessment of the body condition of the donkeys was developed, using a scale from 1 (emaciated) to 9 (obese) (Table 1). The scale took into account the deposition of body fat in different areas by a separate examination of the neck, shoulders, back, ribs, pelvis and rump. Two people condition scored 144 of the donkeys independently, and the repeatability of the scores was computed.

Analysis of data

Johansson and Hildeman (1954) in reviewing the data for cattle reported that the relationship between weight and body measurements was linear when the animals were mature. It was only when growing animals, whose body proportions are changing, were included, that a curvilinear function was appropriate. Linear regression techniques were therefore used to derive 'best' equations for predicting liveweight from the other variables measured. Plots of weight against individual measurements suggested that there was an increase in the variance of weight with increasing values of any of the measurements. The measured values were therefore transformed to logarithms to the base 10 ($\log_{10}$) for use in the regression analyses. Significant improvements in fit, as judged by the adjusted R^2 measure of correlation, were obtained in all cases by using $\log_{10}$ values in place of the original values. Accordingly, only results for $\log_{10}$ values have been reported. Separate prediction equations were produced for immature animals less than three years old, and for adult animals. A nomogram was constructed according to the procedure described by Smith (1966) to assist in practical use of the prediction equation for adult animals.

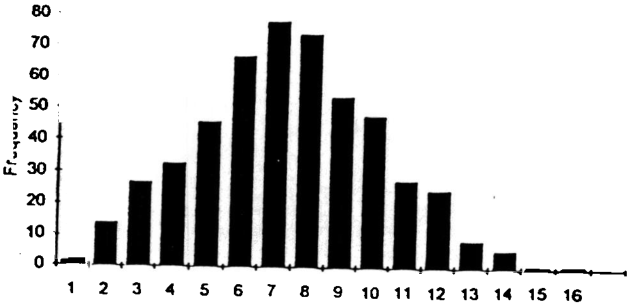


FIG 1: Histogram of the age distribution of 516 donkeys in markets in eight different locations in Morocco

The equation derived by Eley and French (1993) for predicting the liveweight of adult British donkeys: liveweight (kg) = (heart girth $[\mathrm{cm}]^{2·576}$) x (height $[\mathrm{cm}]^{0·24}$)/3968, and that derived for horses by Jones and others (1989): liveweight (kg) = (umbilical girth $[\mathrm{cm}]^{1·78}$) x (length of body from tuber ischii to elbow $[\mathrm{cm}]^{0·97}$)/3011 were tested on the data, and the results were compared with the results predicted by the equation developed in this study. Plots of the estimated and actual liveweights, and histograms of the residuals, defined as the differences between the actual weights and the predicted weights were made.

Results

Characteristics of the donkeys sampled

The sample of adult donkeys contained a good cross-section of the types of donkeys found in Morocco, with a range of liveweights from 74 to 252 kg, height from 82 to 129 cm and length from 64 to 106 cm.

A histogram of the distribution of the ages of the donkeys measured is given in Fig 1. Donkeys over 12 years of age were rarely seen in the markets, suggesting that the life expectancy of working donkeys in Morocco is unlikely to be much over this age.

Practical considerations in the measurement of body parameters

The heart girth, circumference of the cannon bone and height were the easiest measurements to take. Umbilical girth was the most difficult. It tended to be taken at the widest part of the animal rather than over the umbilicus and was most difficult in pregnant or large animals and easiest in young animals.

Estimation of liveweight of mature anima

For the 500 adult donkeys weighing from 74 to 252 kg, the prediction equations were derived by pooling all the data regardless of sex, age, type, body condition and, in the case of females, pregnancy.

All the variables, with the exception of body condition, age and sex were found to have significant effects in an equation with only one predictive variable. The 'best' single predictor variable was the heart girth (adjusted $R^2 = 0·81$):

$$\text{Liveweight (kg)} = \text{heart girth (cm)}^{2·65}/2188$$

followed by umbilical girth (adjusted $R^2 = 0·59$) and length (adjusted $R^2 = 0·58$).

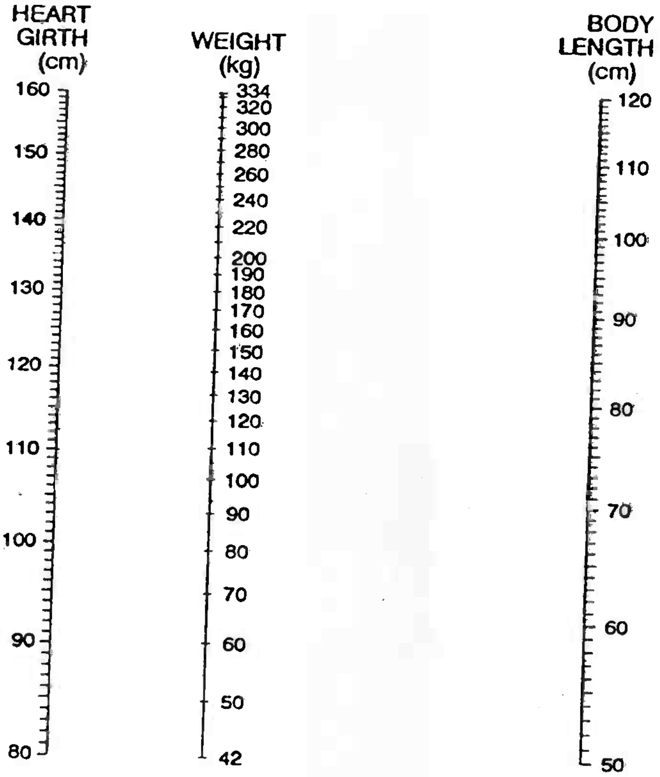


FIG 2: A nomogram for estimating the liveweight of adult donkeys from measurements of heart girth and body length from the tuber ischii to the elbow

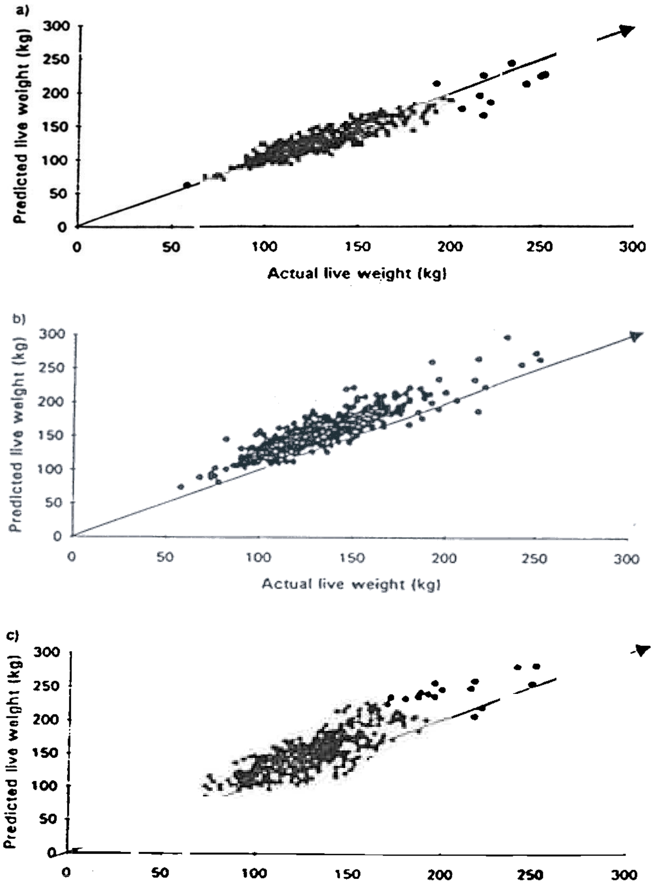


FIG 3: Predicted liveweights against actual liveweights of adult donkeys derived from the present equation (a), the equation of Eley and French (1993) for donkeys (b), and the equation of Jones and others (1989) for horses (c)

When two variables were included, heart girth and length together were better predictors than either umbilical girth with length, or girth with height. The best overall predictive equation using two variables for the adult donkeys was:

$$\text{Liveweight (kg)} = (\text{heart girth [cm]}^{2{\cdot}12}) \times (\text{length [cm]}^{0{\cdot}688})/3801;\ \text{adjusted } R^2 = 0{\cdot}84.$$

This prediction equation was not improved by the inclusion of the additional variable height. About 95 per cent of the residuals lay within ±20 kg, with 73 per cent within ± 10 kg, with an average percentage error in the fitted values of 6·4 per cent.

A nomogram for estimating the liveweight of adult donkeys from the measurements of heart girth and body length was constructed to assist in the practical use of the equation (Fig 2). The inclusion of two variables in the equation marginally improved the accuracy of the prediction, but the addition of further variables gave little extra improvement.

Estimation of liveweight of young animals

The 16 donkeys under three years of age ranged in weight from 52 to 128 kg, and the best variable in a predictor equation with only one variable was umbilical girth:

$$\text{Liveweight (kg)} = \text{umbilical girth (cm)}^{2{\cdot}13}/302;\ \text{adjusted } R^2 = 0{\cdot}77.$$

When two variables were used, umbilical girth and body length gave a better estimate of liveweight than heart girth and length. The best predictive equation for young animals was:

$$\text{Liveweight (kg)} = (\text{umbilical girth [cm]}^{1{\cdot}40}) \times (\text{length [cm]}^{1{\cdot}09})/1000;\ \text{adjusted } R^2 = 0{\cdot}87.$$

Again, the animals' height did not improve any of the prediction equations significantly and it was therefore not included. About 95 per cent of the residuals lay between ± 11 kg, with an average percentage error in fitted values of 6·6 per cent.

Comparison with other predictive equations

The equation for predicting the liveweight of adult donkeys derived by Eley and French (1993) from British donkeys and an equation derived for horses by Jones and others (1989) were tested on the data, and compared with the 'best' prediction equation developed in this study (Figs 3 and 4). Both the other equations overestimated the liveweight of the Moroccan donkeys. The 'horse' equation fitted the data least well of the prediction methods tested, as shown by the wider spread of the residuals (Fig 4).

The equation of Eley and French (1993) for donkeys under two years old also had a tendency to overestimate the liveweight of the young animals in this study (Fig 5).

Body condition score

The condition scoring system was based on a visual appraisal and palpation of the neck, shoulders, back, ribs, pelvis and rump of each animal. Palpation was necessary, particularly in those animals that had a long hair coat, which made the visual appraisal more difficult. There was good agreement between the condition scores assigned by the two people to the 144 donkeys; the scores were the same in 74 per cent of the donkeys, and the maximum difference between the two scorers for any donkey was 1 point. The scoring system was independent of the size or conformation of the donkeys.

The distribution of the body condition scores in the sample of donkeys assessed is given in Fig 6. Most of the donkeys were of moderate to poor condition, 3 to 5 as assessed on the scale from 1 (emaciated) to 9 (obese). Within this range, no correlation was observed between the body condition scores and the differences calculated between the actual liveweight and the liveweight predicted from the equations for adult donkeys.

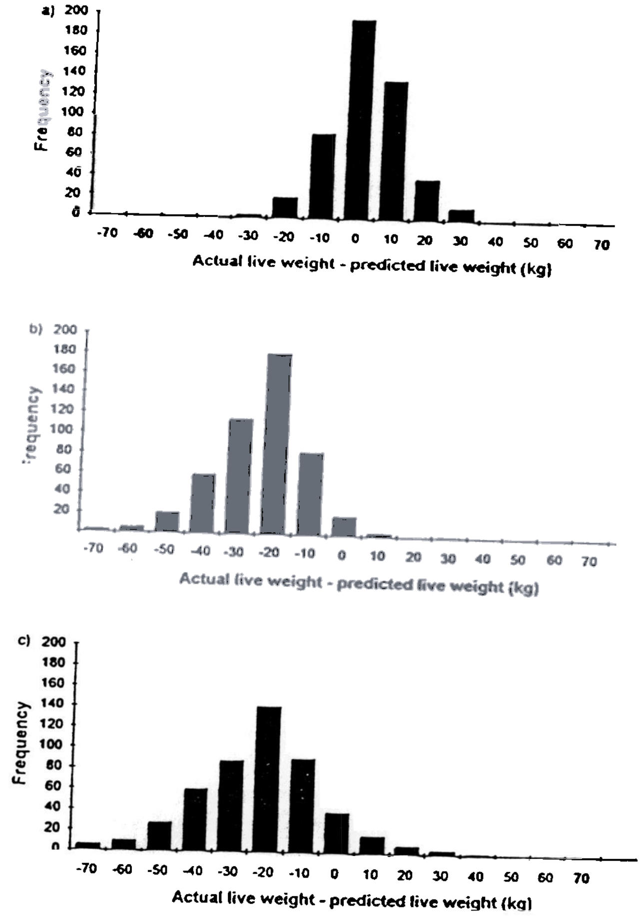


FIG 4: Histograms of residuals for three methods of estimating the liveweight of adult donkeys: the present equation (a), the equation of Eley and French (1993) for adult donkeys (b), and the equation of Jones and others (1989) for horses (c)

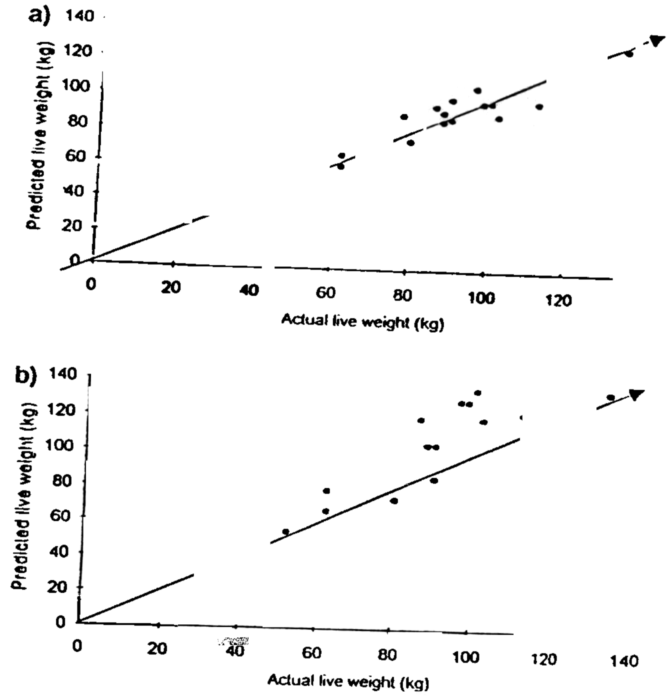


FIG 5: Predicted liveweights against actual liveweights of young donkeys derived from the present equation (a) and the equation of Eley and French (1993) for young donkeys (b)

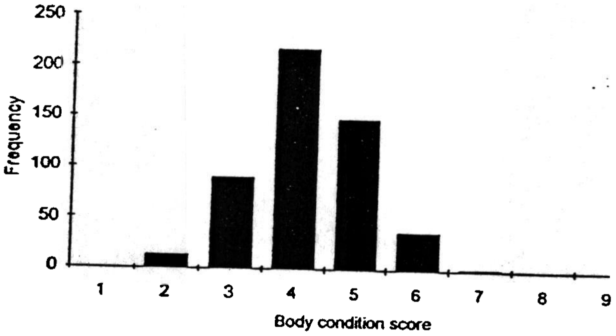


FIG 6: Histogram of the distribution of the body condition scores of 516 donkeys in markets in eight different locations in Morocco

Discussion

As reported by Eley and French (1993) heart girth and height were found to be the easiest and most reliable measurements to take, together with the circumference of the cannon bone. However, unlike the findings of Eley and French (1993) in British donkeys, height was not a good variable to use to predict the liveweight of donkeys in Morocco, and the results suggest that little benefit would be obtained by including it in a prediction equation at the expense of a measurement of length.

The measurement of umbilical girth has been favoured over heart girth for the estimation of the liveweight of horses (Jones and others 1989). In the present study, many of the mature donkeys had large abdomens, probably owing to the high roughage, low quality diets they were fed, rather than to their size and weight, and the measurement of umbilical girth was difficult. This, and the fact that the umbilical girth may vary with the interval since feeding and the quality of the diet fed, probably explains why the prediction equations including umbilical girth as a variable were worse than the equations using heart girth for these adult animals.

Few young donkeys were seen in the souks and the data on these animals are therefore not extensive. An indication that these animals were still developing was the correlation observed in the data between age and the various measurements made. Umbilical girth was as easy to measure as heart girth in these young animals and provided a better estimate of liveweight than heart girth, as Jones and others (1989) had found in mature horses.

The results suggest that it would be preferable to use heart girth rather than umbilical girth as a variable for estimating the liveweight of mature donkeys fed a diet of high roughage content. because they tend to be pot-bellied: for young growing animals umbilical girth may be more satisfactory.

Previous observations of horses (Milner and Hewitt 1969, Jones and others 1989) and donkeys (Neale 1990, Eley and French 1993) indicated that a predictive equation containing two variables produced a better correlation with liveweight than an equation with only one, but that little additional benefit was gained by the inclusion of three or more variables. In the present study, the inclusion of length and umbilical girth gave a better correlation with liveweight ($R^2 = 0{\cdot}87$) than umbilical girth alone ($R^2 = 0{\cdot}77$) for the young animals, but the addition of a second variable (length) in the adult donkeys improved the correlation by very little ($R^2 = 0{\cdot}84$ for heart girth and length together compared with $R^2 = 0{\cdot}81$ for heart girth only). This result is similar to the finding in adult *Bos taurus* cattle by Johansson and Hildeman (1954), who suggested that liveweight could be estimated with about the same accuracy by using heart girth on its own as by using a combination of two of more measurements. The use of more than two predictor variables becomes impractical in field conditions, and little value would be gained by producing more complex equations, particularly because they do not improve the accuracy of prediction significantly.

The equation derived to estimate the liveweight of horses (Jones and others 1989) was unsatisfactory for use with the donkeys in the present study because it overestimated the liveweight.

more, it made use of umbilical girth, which was difficult to
e in the donkeys.

equation of Eley and French (1993) for adult donkeys also
ently overestimated the liveweights of the Moroccan don-
lard working donkeys, particularly in areas where the feed
is irregular, are more likely to be in poor than in good body
on. Unfortunately Eley and French (1993) did not provide
ation on the liveweight or body condition of the animals
mpled. However, if, as is probable, their equation was pro-
from donkeys in good body condition, doing little work, it
be expected to overestimate the liveweight of donkeys in
ly poorer condition, such as those in the present study. It is
ely that there were differences in the age distributions of
lt populations sampled to produce the prediction equations
UK and Morocco, although it is doubtful whether they
have greatly influenced the effectiveness of the equation.
eys of working donkeys in other Mediterranean countries
Tunisia and Turkey) by the International Donkey
on Trust (Bliss 1989, Svendsen 1991) have indicated that
rage life span of a working donkey in these areas is rarely
years. The age range of the sample of donkeys measured
resent study suggests that in Morocco too the life span of
s is short, in comparison with the average life span
sh donkeys of 37 years reported by Bliss (1989) and
babwean donkeys of about 20 years (E. M. Nengomasha,
l communication).
ough the equations derived in the present study for adult
ng donkeys performed well on the data, this is to be
d because the equations were derived from measurements
ng to those particular donkeys. The ultimate validation,
e, must rest on testing other samples of working donkeys
parts of the world.

Acknowledgements. – The authors are grateful for the financial support given by the International Donkey Protection Trust, and the British Overseas Development Administration, and the technical assistance of the Society for the Protection of Animals Abroad in Morocco, which made this work possible. They thank M. Bakkoury, A. Belemlih and A. Prentis for their assistance in Morocco, A. E. Hunter for statistical advice and P. R. Lawrence for making the nomogram.

References

BLISS. D. H. (1989) The Professional Handbook of the Donkey. Ed. E. D. Svendsen. 2nd edn. Sidmouth. The Donkey Sanctuary. p 95

BRODY. S. (1945) Bioenergetics and Growth. Baltimore. Waverley. p 634

BURT. A. W. A. (1957) *Journal of Dairy Research* 24. 144

CARROLL, C. L. & HUNTINGTON. P. J. (1988) *Equine Veterinary Journal* 20. 41

DAVIS. H. P.. SWETT. W. W. & HARVEY W. R. (1961) *Research Bulletin of Nebraska Agricultural Experimental Station* 194. 1

ELEY. J. L. & FRENCH. J. M. (1993) *Veterinary Record* 132, 250

JOHANSSON. I. & HILDEMAN. S. E. (1954) *Animal Breeding Abstracts* 22, 1

JOHNSON. D. W. (1940) Minnesota Agricultural Experimental Station Extension Folder. Minnesota Agricultural Experimental Station. p 70

JONES. R. S.. LAWRENCE, T. L. J.. VEEVERS. A.. CLEAVE, N. & HALL, J. (1989) *Veterinary Record* 125, 549

MILNER, J. & HEWITT. D. (1969) *Canadian Veterinary Journal* 10, 314

NEALE, S. C. (1990) MSc thesis. University of Bristol School of Veterinary Science

SMITH, C. A. B. (1966) Biomathematics: the principles of mathematics for students of biological and general science. 4th edn. Vol 1. London. Charles Griffin. p 163

SVENDSEN. E. D. (1991) Donkeys. Mules and Horses in Tropical Agricultural Development. Eds D. Fielding. R. A. Pearson. Edinburgh. Centre for Tropical Veterinary Medicine. p 181

WANDERSTOCK. J. J. & SALISBURY. G. W. (1946) *Journal of Animal Science* 5. 264

Short Communications

avioural and cortisol response of gs and sheep during transport

R. H. Bradshaw, S. J. G. Hall, D. M. Broom

Record (1996) **138**, 233-234

d sheep are usually transported during the course of their
ious behavioural and physiological effects of the trans-
process have been reported in both pigs (Warriss and
91, Geers and others 1994) and sheep (Douglas-Hudson
an 1993, Knowles and others 1993, 1994). Journeys to
are frequently of relatively short duration (a few hours
and road conditions vary. In the present study the
ral and cortisol response of pigs and sheep were com-
ring short road journeys in order to establish whether
uidelines should be species specific and whether differ-
stic species are sensitive to specific types of journey
he degree of 'roughness').
0 kg pigs and four 60 kg sheep were used, each social
nprising individuals which were familiar with each other.
Each species was transported on alternate days in a car-towed twin-axle horse trailer (195 x 160 cm) on journeys characterised as 'rough' and 'smooth' (by means of an accelerometer). The rough condition involved journeys on minor roads in Cambridgeshire while the smooth condition consisted of journeys on the motorway. Each group travelled a distance of 761 km comprising 16 40 minute journeys (eight rough and eight smooth). The first journey type (rough or smooth) was alternated daily, with a total of two rough and two smooth journeys being conducted each day. A 20 minute rest period was allowed between each journey during which time the trailer remained stationary. Pigs and sheep were also loaded on a separate day. each for four hours, but the trailer remained stationary (control). In all cases fresh straw was provided at the beginning of each day on the trailer floor.

Behaviour was recorded by means of a remote controlled video camera mounted in the trailer and saliva samples were taken at the beginning and end of each journey for analysis of cortisol. The total number of minutes either lying. standing or walking was recorded for each animal and a mean was then calculated for the four animals. This mean was then expressed as a percentage of the total journey time. Mean frequency of social interaction, retching and vomiting were also calculated for each type of journey. Salivary cortisol was measured using an enzyme-linked immunosorbent assay (ELISA) (Cooper and others 1989). Sheep were fed ad libitum up to the point of loading and pigs were fed at the beginning of each day three hours prior to loading.

Analysis of accelerometer data revealed that there were four times more acceleration events during rough journeys (mean num-

---

adshaw, S. J. G. Hall, D. M. Broom, Animal Welfare and
nimal Interactions Group, Department of Clinical Veterinary
Madingley Road, Cambridge CB3 0ES

Appendix 5

Use of an *in vitro* gas production technique with faeces as inoculant to assess tropical forage quality for equids

R.T.S. Kirkhope[1] and R.S. Lowman[2]

[1] Centre for Tropical Veterinary Medicine, [2] Department of Veterinary Clinical Studies, University of Edinburgh, Easter Bush, Roslin, Midlothian EH25 9RG, United Kingdom

Introduction

In tropical areas reliable estimation of feedstuff nutritional value often proves difficult, and many feed resources remain poorly characterised. Recording *in vitro* gas production from feedstuffs, using ceacal digesta as a gut microbial source, is a promising new method for analysing digestion kinetics in equids. However, this demands caecal fistulation. Substituting caecal fluid with faeces provides a potential non-invasive alternative. These experiments assessed the ability of equine faeces to assume this role. In the first study, donkey and pony faeces were compared to determine any differences in gas production and degradation characteristics between species. In the second study, donkey faeces and pony caecal digesta were compared as inoculum sources, and their respective abilities to predict *in vivo* digestibility were determined.

Material and Methods.

Naked oats (NO) and four forages (grass pellets (GP), alfalfa hay (AH), oat straw (OS) and millet stover (MS)), all of known *in-vivo* digestibility, were incubated *in vitro* with either a faecal or a caecal digesta inoculum.

In study 1, faeces were collected simultaneously from 4 donkeys or 4 Shetland ponies, all stabled and on a hay diet. Faeces were mixed 1:1 with modified Van Soest medium to obtain a similar dry matter (DM) content to that of the caecal inoculum. 125 ml bottles, containing 90 ml Van Soest medium and 0.75 g DM feed substrate, were inoculated with homogenised, strained, 10 ml aliquots of the prepared inoculum. Bottles were incubated for 72 hours during which time headspace pressure and gas production were measured at regular intervals according to the technique of Theodorou *et al.* (1994). At the end of the incubation period undegraded feedstuff DM was determined, to enable calculation of *in vitro* degradability.

In study 2, donkey faeces, and caecal digesta from 3 fistulated, hay-fed, Welsh-cross ponies, were collected simultaneously and processed as above. Bottles were incubated for 120 hours, to ensure an asymptote for gas production was obtained. Cumulative gas production data from this study were fitted to the model of France *et al.* (1993) *i.e.* $Y = A\,(1 - e^{-b(t-T) - c(\sqrt{t} - \sqrt{T})})$, and the resulting parameters used to predict *in vivo* digestibility for each feedstuff.

Results.

Total gas production was highly correlated with the proportion of feedstuff degraded ($r^2 = 0.84$) ($p < 0.001$). Feedstuffs were succesfully ranked according to their apparent *in vivo* digestibilities using cumulative gas production (Figure 1) or degradability data.

For all feeds studied, cumulative gas production profiles and total gas production were similar when using donkey or pony faeces as inoculum source ($r^2 > 0.99$). Cumulative gas production was also similar when comparing donkey faeces with caecal fluid ($r^2 > 0.95$) (Figure 2). However total gas production (ml) after 120 hours was greater with donkey faecal compared to caecal inoculum for GP (170 ± 4.13 vs. 144 ± 2.56), AH (148 ± 2.82 vs. 130 ± 3.5), OS (138 ± 2.90 vs. 119 ± 2.21)and MS (108 ± 4.47 vs. 82 ± 3.25)($p < 0.01$). Total gas production using Naked Oats as feed substrate did not significantly differ between inocula (225 ± 6.36 vs. 221 ± 7.15).

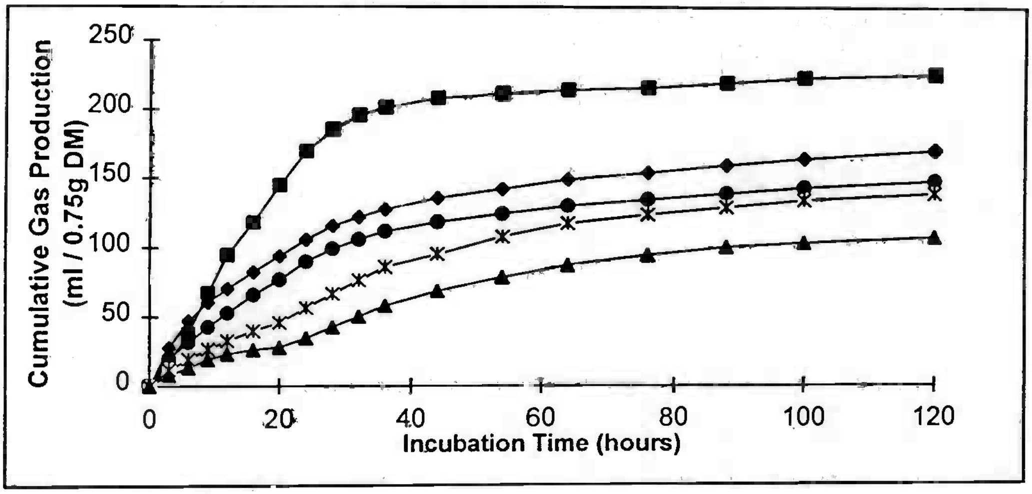


Figure 1: Cumulative gas production (ml) from 0.75 g DM naked oats (squares), grass pellets (diamonds), alfalfa hay (circles), oat straw (stars) and millet stover (triangles), during 120 hours incubation with donkey faecal inoculum.

Degradability of substrate DM was similar in donkey faecal and caecal incubations for NO, GP and AH, but was greater with faecal inoculum for the more fibrous feeds OS and MS (Table 1). Fitting of the model of France *et al.* (1993) to the data, for the prediction of *in vivo* digestibilities, resulted in an underestimation of apparent *in vivo* digestibility for all feeds.

Table 1: Percentage *in vitro* degradability (± s.e.m.), predicted *in vivo* digestibility using the model of France *et al.*(1993) and measured apparent *in vivo* DM digestibility for each feed.

		Naked Oats	Grass Pellets	Alfalfa Hay	Oat Straw	Millet Stover
In vitro degradability (%)	Donkey Faeces	93.5±1.1	74.1±0.5	74.3±0.6	69.2±0.2	47.0±0.1
	Pony Caecal Fluid	93.8±1.2	75.2±1.8	73.7±0.8	63.9±0.3	39.7±0.8
	Significance	NS	NS	NS	$p < 0.001$	$p < 0.001$
Predicted *in vivo* digestibility (%)	Donkey Faeces	68.0	49.5	48.1	36.0	23.4
	Pony Caecal Fluid	69.0	51.3	48.5	31.8	18.4
In vivo DM digestibility (%)	Donkey	—	66	67	50	31
	Pony	—	64	68	48	—
	Horse	87	—	69	48	—

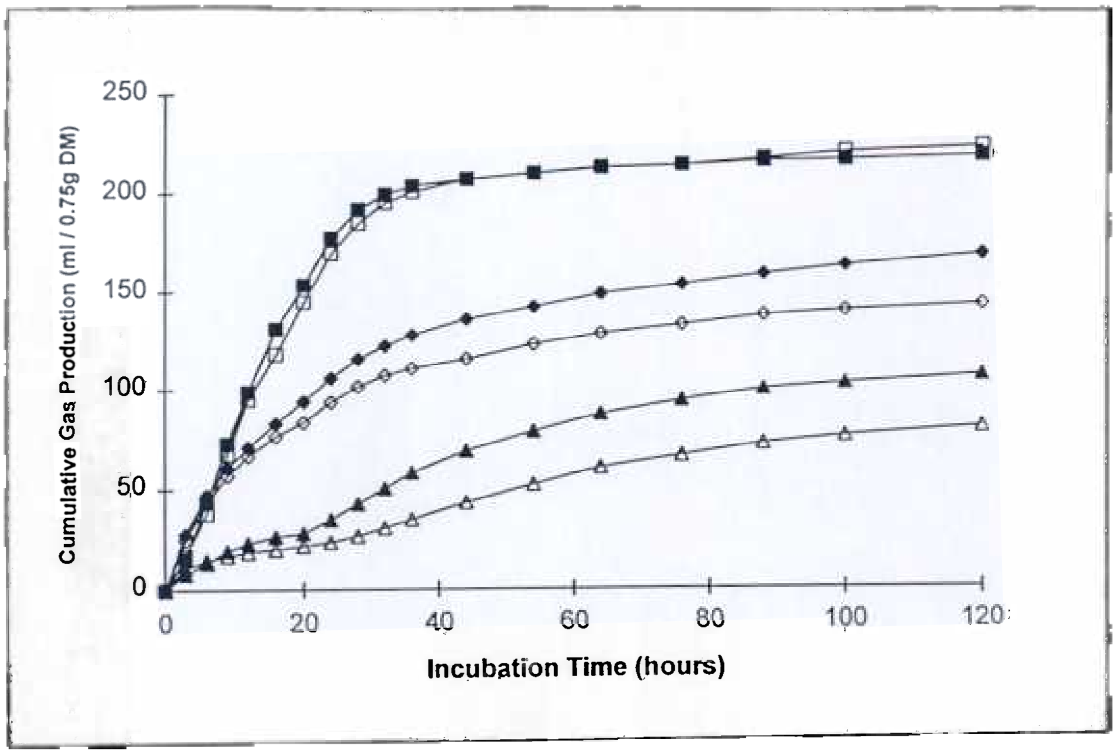


Figure 2: Cumulative gas production (ml) from 0.75g samples of naked oats (squares), grass pellets (diamonds) and millet stover (triangles) when incubated with donkey faeces (solid) or pony caecal digesta.

Conclusions

- Feedstuffs were successfully ranked acording to their relative *in vivo* digestibilities using the gas production technique with both caecal and faecal inocula. This suggests the technique could provide a useful means of assessing nutritive value of forages in tropical husbandry systems.
- Little difference appears to exist in *in vitro* fermentation characteristics between pony and donkey faeces derived from animals on a similar diet.
- Gas production and DM degradation values were higher for the more fibrous feedstuffs when using faecal inoculum in comparison to caecal fluid. This suggests an increased ability of the faecal microbes to digest fibrous feed components.
- The ruminant-based equations of France *et al.* (1993) for the prediction of *in-vivo* digestibility proved inadequate in this study. New or revised models specifically designed for use with *in-vitro* fermentation data from equids may be required.

Acknowledgements

R.T.S. Kirkhope was in receipt of a BSAS Summer Placement scholarship.

References

France, J., Dhanoa, M.S., Theodorou, M.K., Lister, S.J., Davies, D.R. and Isac, D. (1993) Amodel to interpret gas accumulation profiles associated with in-vitro degradation of ruminant feeds. *Journal of Theoretical Biology* **163**: 99-111
Theodorou, M.K., Williams, B.A., Dhanoa, M.S., McAllan, A.B. and France, J. (1994) A simple gas production method using a pressure transducer technique to determine the fermentation kinetics of ruminant feeds. *Animal Feed Science & Technolgy*. **48**: 185-197