FACTORS AFFECTING FEED INTAKE, ENERGY EXPENDITURE AND WORK OUTPUT OF OXEN AND BULLS USED FOR DRAUGHT PURPOSES IN SEMI-ARID WEST AFRICA

ABDOU FALL

PhD

UNIVERSITY OF EDINBURGH

1995

DECLARATION

I, **Abdou FALL**, hereby, declare that the experiments described herein and the composition of this thesis have been completed by myself.

Abdou FALL

TABLE OF CONTENTS

ABSTRACT

The objectives of this thesis were to i) determine the energy expenditure of draught oxen performing common farm operations, ii) establish the relationships between work on intake and digestibility of feeds by draught oxen, iii) investigate the effect of body condition before work and live weight losses during work on work output, and iv) investigate the implications of heat stress on draught oxen in semi-arid areas. The ultimate aim of this study was to generate information necessary for the design of feeding and working strategies for draught animals in semi-arid areas. To meet these objectives four experiments were conducted at the ICRISAT Sahelian Centre, with the collaboration of the International Livestock Centre for Africa.

In the first experiment the Oxylog, a portable breath by breath gas analyser, was used on 7 animals to determine their standing metabolic rate, their energy cost of walking on soils of different consistencies, and their efficiency of doing work, i.e., ploughing and carting. The average standing metabolic rate of animals was 487 (±10.6) kJ/kg $LW^{0.75}$. The consistency of the soil on which animals were working had a marked effect on their energy cost of walking which was 1.59 (±0.069), 2.15 (±0.084) and 1.0 (±0.10) J/m/kg live weight on unploughed land, ploughed land and laterite tracks, respectively. The efficiency of ploughing sandy soils 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.

In the second experiment intake of millet stover, water intake, live weight, plasma concentrations of T3, T4 and urea-nitrogen were measured on 18 animals that worked for 0, 2 or 4 h/day in sequence during three 3-week experimental periods. In addition to these variables, the digestibility and rate of passage of feeds through the digestive tract were measured during the third experiment on 12 animals working either 0, 2.5 or 5 h/day in sequence during three 2-week experimental periods. In the fourth experiment feed intake was measured on 18 animals of different body condition that worked 4 days a week for 7 weeks. The absence of effect of work on intake of millet stover was consistent during these experiments. The efficiency of utilisation of eaten roughages and the rate of passage of the digesta in the gastro-intestinal tract were not influenced by work either. This suggest that the nutrient supply from intake of roughages by working oxen and bulls is unlikely to be sufficient to compensate for the extra energy expended during work. Feed intake was however significantly affected by the quality of the millet stover fed and by the body condition of the animal. The level of intake of millet stover was proportional to the amount of leaves in the stover. Animals in bad condition ate more millet stover than animals in good body condition. Feed intake improved also as work progressed in the second and third experiment. Because animals could not increase feed intake they mobilised their body reserves to perform work. Hence body weight losses were seen during all experiments. Animals consumed more water on working days than on days they were at-rest in the shade. Rectal temperature, respiration rate, climate parameters and work output were measured during the second, third and fourth experiments. The heat stress that working animals were subjected to did not interfere with their digestive physiology, however it negatively affected their work performance. Repeatability estimates were 0.19 for rectal temperature before work, 0.29 for the maximum increase in rectal temeperature during work, and 0.16 for rectal temperature during work. There was a marked variation in the capacity of individual oxen to cope with heat stress. Fatter animals had more difficulties in maintaining homeostasis than leaner animals.

In the fourth experiment 18 oxen were allotted to 3 treatment groups according to their body condition: poor, medium and good. Work performance, speed of work and weight losses were measured during 7 weeks when animals worked 4 days/week pulling loads equivalent to 12.5 kgf/100 kg live weight. Work performance was more dependent on live weight than on body condition. Also live weight losses did not negatively influence work performance. Power output improved during the course of the experiment while animals were undergoing weight losses.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to my supervisor, **Anne Pearson.** She has been a constant source of scientific support, advice and encouragement throughout the course of this study. Her special kindness and friendship contributed a great deal to the successful completion of this work

Peter Lawrence deserves special thanks for his invaluable scientific contribution to this work. He set up the instrumentation systems used in this study to measure the energy expenditure of animals using the modified oxylog and to monitor work performance and body temperatures. His comments on the preliminary results are also appreciated.

My thanks go also to **Salvador Fernandez** who supervised this work in Niger. He constantly supported this project during its implementation and his scientific advice is sincerely appreciated. I extent my thanks to all the scientists and personel at the ILCA programme in Niger and their families for their friendship towards my family during our stay in Niger.

I am also indebted to **Tony Smith** at the CTVM for his constructive comments and advice.

This study would not have been completed without the dedication of the workers at the ICRISAT Sahelian Centre in Niger with the excellent supervision of Midou Amadou, Abdoulaye Soumaila and Arona Garba. Boube, Boubacar, Bouzou, Dioumassi, Mamadou, Moustapha and Alpha deserve my gratitude for their hard work under stressful conditions.

My thanks are extended to **Bob Archibald** for his invaluable assistance during the laboratory work. **Mary Booth** and **Rick Clemence** deserve my thanks for their friendship.

I am indebted to the Overseas Development Administration of the United Kingdom for providing the funds to carry out this study. I am also grateful to the International Centre for Africa for its financial and adminitrative support and the use of their facilities in Niger. My thanks go also to The British Council in Senegal for their financial support towards the fees and tuition for my enrolment at the University of Edinburgh.

I am also indebted to the Director General of ISRA, **A. LY**, for accepting my study leave for three years to carry out this work.

I had usefull interactions with **Pamela Mueller** in Niger and in Scotland. She deserves my thanks. I also appreciated the companionship of **Tidiane Ngaido** while I was in Niger.

My special and sincere thanks go to my wife and kids for their patience during three years I was away to complete this work.

LIST OF ABBREVIATIONS

ADF:	Acid Detergent Fibre
ADP:	Adenosine DiPhosphate
ARC:	Agricultural Research Council
AT:	Ambient Temperature
ATP:	Adenosine TriPhosphate
^oC:	Degree Celsius
Ca:	Calcium
Cr.:	Chromium
CO_2	Carbon Dioxide
CV:	Coefficient of variation
CTVM:	Centre for Tropical Veterinary Medicine
d:	Day
DADF:	Distance Averaged Draught Force
DAP:	Draught Animal Power
DM:	Dry Matter
DMI:	Dry Matter Intake
E_f	Efficiency of doing work
Equa.	Equation
E_w	Energy cost of walking
EWT:	Elapsed Working Time
FAO:	Food and Agriculture Organisation
g:	Gramme
GE:	Gross Energy
h:	Hours
H:	Heat production
HEM:	Hemicellulose
H_2O:	Water
IBC:	Initial Body Condition
ICRISAT:	International Crop Research Institute for Semi-Arid Tropics

ID:	Integrate and Display
ILCA:	International Livestock Centre for Africa
J:	Joule
k_1:	Rate-constant, rate of passage of digesta in the rumen
k_2:	Rate-constant, rate of passage of digesta in the lower tract
kg:	Kilogramme
kJ:	Kilojoule
km:	Kilometre
Mg:	Magnesium
l:	Litre
LCFA:	Long Chain Fatty Acid
LSR:	Leaf stem ratio
LW:	Live weight
m:	Metre
ME:	Metabolisable Energy
MIRT:	Maximum Increase in Rectal Temperature
min:	Minute
mm:	Millimetre
mmol:	Millimole
MJ:	Megajoule
MRM:	Metabolic Rate Monitor
MRT:	Mean Retention Time
n:	Number of observations
N:	Newton
NDF:	Neutral Detergent Fibre
NE:	Net Energy
nmol	Nanomole
no.	Number
NS:	Not significant
O_2	Oxygen
OM:	Organic Matter

P:	Phosphorus
PUN:	Plasma Urea-N
RAM:	Rest in the Morning
RPM:	Rest in the Afternoon
RH:	Relative Humidity
RQ:	Respiration Quotient
RR:	Respiration rate
RT:	Rectal Temperature
s:	Second
SAS:	Statitical Analysis Systems
s.e.:	Standard error
SMR:	Standing Metabolic Rate
T_3:	Triiodothyronine
T_4	Thyroxin
TADF:	Time Averaged Draught Force
THI:	Temperature Humidity Index
TT:	Time of first appereance of the marker
UK:	United Kindom
USA:	United State Of America
VFI:	Voluntary Feed Intake
W:	Watt
WAM:	Work in the morning
WPM:	Work in the Afternoon

GLOSSARY OF UNITS

Calorie (cal): The amount of heat required to increase the temperature of one gram of water by one degree Centigrade (from 14.5 to 15.5 oC in physiological studies) when the specific heat of water is 4.184 j/g.

Joule (J): Work done when a body is moved 1m against an opposing force of 1 Newton,
1 calorie = 4.184 Joules.
1 kJ = 1000 J, 1 MJ = 1 000 000 J.

Kilogram-force (kgf): 1 kgf = 10 Newtons

Newton: Thhe SI unit of force that, acting on a mass of one kilogram, increases its velocity by one metre per second every second along the direction that it acts

Watt (W): 1 W = 1 Joule per second.

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Draught animal power has been harnessed for agricultural purposes for thousands of years. Although draught animal technology has been superseded by tractors in the developed world during the last 50 years, it remains to this day a relevant farm technology in many parts of the developing world mainly for economic and agroecological reasons . Purchase and maintenance costs of tractors are high in many countries in sub-Saharan Africa. These factors confer a comparative advantage to draught animal technology which is less expensive than using tractor power for small-scale farmers making up the majority of rural communities. In addition, certain fields such as hillsides and muddy river valleys are out of reach of tractors. Draught animals are therefore the only means, other than hand labour, farmers have to cultivate these lands.

Draught animal power has been 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 in sub-Sahara Africa. Agricultural production in this region continues to rely primarily on humans for its power needs. Statistics in 1987 suggested that 89% of power was provided by humans while draught animals supplied 10% of the farm power input (FAO, 1987).

Draught animal technology has been qualified by Starkey (1994) as an ecologically sustainable means of increasing agricultural production, reducing human drudgery and improving the quality of rural life. The need for its promotion in sub-Saharan Africa to fill the gap between the deteriorating level of food production and the increasing demand for food cannot be overemphasised. This is particularly true in semi-arid areas where timeliness in cropping operations is fundamental for successful cropping because of the short growing season prevailing in these areas. The low and erratic rainfall regime constrain farmers to prepare land and to plant rapidly at the onset of the rainy season to supply maximum soil moisture to the plant. In these situations, draught animal power becomes critical to supplement human energy so that field operations can be done at the right time to reduce the risk of crop failure and to secure a stable yield. Draught animal power has proved also very effective, in this zone, to increase agricultural production by enabling the extension of the surface areas cultivated.

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

Besides the nutritional constraints related to the shortage of food and to the low quality of the feed available, nutrient supply to draught animals for work may be constrained by the limited time available for these animals to eat and to thoroughly comminute feeds. This may adversely affect the intake and digestibility of feeds. In addition, high ambient temperatures prevailing in semi-arid areas may also combine with the increased metabolic heat due to work to cause severe heat stress to the working animal. This may depress work output and feed intake. The correction of the feed deficit and nutrient deficiencies by supplementing draught animals' rations with high quality feeds is the logical action to be taken. However, many farmers keeping draught animals in semi-arid areas do not have easy access to good quality feeds because of their scarcity and high price. Farmers, generally, rather exploit the cycles of nutrient deposition and mobilisation in the management of their draught animals. Cattle in semi-arid areas have adapted to the seasonality in feed supply by building up body reserves during periods of plentiful food. These reserves are drawn upon during periods of feed deficit for work as well as foetal growth and calf feeding.

The identification of feeding and management systems for draught animals in a farming system requires information on the availability and the nutritive value of existing feed resources over the year, knowledge of the utilisation of these feeds by draught animals and information on the nutrient requirements of draught animals for work. There is little information on the energy requirements of draught oxen working on sandy soils under hot conditions in semi-arid areas. Neither have the patterns of 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, been investigated in semi-arid areas where oxen are fed on cereal crop residues. Therefore the objectives of this thesis are to:

- determine the energy expenditure of draught oxen working on sandy soils, performing common agricultural tasks, so that their energy requirements can be determined;

- establish the relationships between work and intake and digestibility of roughages by draught oxen;

- investigate the effect of body condition before work and live weight losses during work on work performance,
- investigate the implications of heat stress on draught oxen in semi-arid areas.

This information will allow informed decisions to be made on the feeding and management of draught animals in semi-arid areas.

Four experiments were conducted at the ICRISAT Sahelian Centre in Niger between 1993 and 1994 to address the above issues.

Experiment 1 determined the energy cost of walking on soils of different consistencies and the efficiencies of doing work.

Experiment 2 was designed to establish the relationships between work and intake of millet stover.

Experiment 3 investigated the effect of work on intake, digestibility and gastrointestinal rate of passage of feeds in draught oxen fed on millet stover.

Experiment 4 investigated the effect of body condition before work and the body weight losses during work on work performance of draught oxen.

In addition to the above objectives, Experiments 2, 3 and 4 were designed to assess heat stress in draught animals and to evaluate the association between work output and heat stress. Each topic is dealt with in separate chapters (Chapters 2, 3, 4 and 5). Each of these chapters includes a literature review on the topic of interest, the objectives and material and methods of the experiment(s), the results and discussion. Experiment 1 is reported in Chapter 2. Details of and results from Experiments 2 and 3 were combined to form Chapter 3 dealing with the effect of work on the digestive physiology of draught oxen fed on crop residues. Experiment 4 is illustrated and discussed in Chapter 4. The extent of heat stress in draught oxen working under hot conditions and how this affects work performance is assessed in Chapter 5. Recommendations for research needs based on the findings of this study are formulated in Chapter 6.

CHAPTER II

ENERGY EXPENDITURE OF OXEN WORKING IN SEMI-ARID AREAS OF AFRICA

2.1. Introduction

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

The adaptation of portable gas analysers to measure O_2 consumption by draught animals and the design of instrumentation to measure work performance contributed to the accumulation of a body of knowledge that can form the basis of more sound predictions of the work performance and the nutrient requirements of draught animals. For instance, now it is recognised that the estimation of energy expenditure of draught animals as 2.7 times the maintenance expenditure (FAO, 1972; Goe and McDowell, 1980) was an overestimation and that values between 1.3 and 1.8 times maintenance (Lawrence, 1985; Barton, 1987; Pearson, 1989) are more realistic estimates. However, although draught animal science has progressed from its infancy state in the 70's to a more adolescent stage (Lawrence and Zerbini, 1993), there are still areas that need more research if sound feeding strategies of draught oxen are to be formulated. The determination of the energy costs of different activities occurring during work is one of the topics that need further investigation (Lawrence and Becker, 1994).

This chapter deals with the energy expenditure of draught oxen in semi-arid areas. First, the extent of use of draught oxen in semi-arid areas in sub-Saharan Africa is assessed. Second, the nutrient requirements of draught oxen and the instrumentation developed to monitor work output are reviewed. Third, methods of measuring the energy expenditure of animals and their application to working animals are examined. Finally, this chapter gives details of and results obtained from an experiment that was carried out to investigate the energy cost of walking on ground surfaces of different consistencies and the energy cost of doing work on these surfaces.

2.2. Literature review

2.2.1. Patterns of draught oxen use in semi-arid areas

The agroecological zone where the number of growing days of the vegetation range between 90 to 180 days is classified as semi-arid. The over-riding climatic features in this zone are the low and variable rainfall and the resulting short crop growing season and the high ambient temperatures. The lower limit of semi-arid areas is defined by the 500 mm isohyet above which sustained cropping becomes feasible. The upper limit, separating the semi-arid and the sub-humid zone, is more difficult to set and has been variously interpreted over the range of 800 and 1200 mm (Montgolfier-Koevi and Vlavonou, 1981). Semi-arid areas that make up 18.1% of agroecological zones in tropical Africa (Janhke, 1982) encompass the whole or parts of many countries in West, Central and Southern Africa. Semi-arid areas present a diversity of environmental constraints and opportunities to crop production due to differences in soils characteristics and the length of the growing season. These factors, among others, have also influenced the extent of use of draught oxen in semi-arid areas.

In the drier part of semi-arid areas soils are found that become very hard in the dry season. They are generally deficient in phosphorus, low in organic matter and have bulk densities that limit root development (Klaij and Serafini, 1988). The cropping system on these soils is based on pearl millet and cowpea. Although tillage of these soils may secure increased yield through enhanced rooting and greater access to moisture and fertiliser, this is not a common practice in the drier part of the semi-arid areas. Because of the short growing season, the costs of delayed planting may outweigh the beneficial effects of soil preparation. As a result, most farmers in these areas have opted for direct planting or reduced tillage. Moreover, returns from subsistence millet production may not secure the profitability of investments involved in field mechanisation as compared with revenues generated from growing cash crops such as groundnut and cotton. In these areas draught oxen are mainly used for farm transport throughout the year.

More humid areas in the semi-arid zone present more opportunities for the use of draught oxen. Soils in these areas are heavier and therefore require tillage. Moreover there is less competition between timeliness in planting and the degree of soil preparation because the growing season is longer than in the drier parts of the semi-arid areas. The use of draught oxen has been successfully promoted in these areas to boost cotton and groundnut production. They are commonly used for ploughing, ridging, earthing up and weeding. This is illustrated by the typical pattern of oxen use in the semi-areas in Mali reported by Khibe and Bartholomew (1993, Table 1). The amount of time worked by oxen during the year reported by these authors (9 weeks) can be extended if transport is included in the daily activities of oxen. It is also common in these areas for farmers with surplus oxen to hire out some of their animals. Extensive use of draught oxen occurs however in some high potential farming systems in semi-arid areas. For instance, along the main rivers (Senegal, Niger) in the west African semi-arid areas, oxen can be used for cultivation of two cropping cycles each year in intensive rice production. Even if transport and ox-hiring are taken into account, draught oxen are not yet fully used throughout the year in semi-arid areas and therefore they stay idle during many months. This reduces the efficiency of their use. The promotion of other uses of draught animal power such as water lifting and the activation of stationary devices should be encouraged in these areas to make best use of available resources.

Table 1.

Number of hours worked per day, number of days worked per year, draught force exerted and working speed during different types of work by a pair of draught oxen in the semi-arid areas in Mali (Khibe and Bartholomew, 1993).

Type of work	Number of hours worked per day	Number of days worked	Draught force (N)	Speed (m/s)
Scarification	4.2	3.4	52	1.07
Ploughing	2.9	2.7	825	0.85
Ridging	4.6	16.2	835	0.74
Planting		0.9	292	
Weeding	3.5	11.2	656	0.77
Earthing-up	4.7	2.7	708	0.72

Farmers in semi-arid areas are confronted with a widespread degradation of their soils that seriously compromises the required increase in agricultural output to alleviate the continuing food shortage experienced in these zones. Improved soil and water management techniques have been advocated in these areas to secure sustained agricultural production. Techniques of conservation tillage recommended for these zones include ridging, no-till-tie-ridging, and tine cultivation (Stevens, 1994). A shortage of power is one of the major factors constraining the adoption of these innovations using animal-drawn implements (Sene and Garin, 1990). Well-fed draught oxen with adequate liveweight are required if a large scale adoption of these techniques is to be realised.

2.2.2. Breeds of draught oxen and work capacity

The major cattle breeds used for draught purposes in semi-arid areas are of the *Bos indicus* (zebu) type. Examples of breeds commonly used are the Senegalese Fulani, the Sudanese Fulani (Mali), the White Fulani or Bunaji and the Sokoto Gudali. Ndama cattle (*Bos taurus*) and their crosses with the zebu breeds such as the Diakore in Senegal and the Mere in Mali are also used as draught animals (Munzinger, 1982). The adult live weight of the zebu breeds range between 250 to 450 kg. The Diali breed used in this study is found in the valley of the Niger River in Niger and in nearby parts of Nigeria. The average height of the Diali bull is 135-139 cm with an average live weight (LW) of 300-350 kg (Felius, 1985).

The required LW of the individual ox in the pair to perform common field operations in semi-arids areas derived from Table 1 range from 140 to 380 kg assuming a level of pull equivalent to 11% of LW. Teleni and Hogan (1989) recommended an upper limit of draught load equivalent to 11% of LW for animals working more than 3 h in ambient temperatures of 27-34 °C. Draught forces required for cartage are more variable because they depend on the load. It is therefore apparent that breeds in semi-arid areas in sub-Saharan Africa have the potential capacity to perform most of the common agricultural operations provided they are in good health and their nutrient requirements are met.

2.2.3. Nutrient requirements for draught oxen

Protein and minerals

Pearson and Lawrence (1992) gave evidence of the limited increased requirements for protein as result of work. In Costa Rica, they investigated the nitrogen balance of 6 six steers fed on hay (6 kg/day) and concentrate (3 kg/day).

They measured nitrogen excretion in both urine and faeces during working and resting periods. There was no significant difference in urinary nitrogen in the weeks during and after work as compared to weeks prior to work. It was concluded that there was little extra requirement for protein during work. It is also assumed that the feed supplement given to minimise weight losses will supply the working oxen with sufficient protein (Lawrence, 1985).

However proteins may be involved in the supply of energy to the working animal. Draught animals are usually fed on low quality diets that limit metabolisable energy (ME) intake. As a result they lose weight during work because tissues are catabolised to supply energy-yielding nutrients that contribute to ATP production. For amino acids to be used in the energy pool that fuels muscle contraction, it is required that the ratio of energy-yielding nutrients to amino acids be reduced or that amino acids are not in a proportion compatible with protein synthesis (Teleni and Hogan, 1989). However amino acids are also likely to be important because of their role in improving the rumen environment of oxen fed on poor quality roughage. Intake and digestion of these feeds can be enhanced by the provision of a source of nitrogen that stimulates microbial growth in the rumen through the increased ammonia concentration in the rumen fluid.

There is not yet any evidence of increased requirements of draught animals for minerals and vitamins as a result of work. However the need for extra minerals, particularly those associated with energy metabolism (Ca, Mg, and P), is likely to occur in working animals (Pearson and Dijkman, 1994). Moreover, animals working under hot conditions will have an extra need for minerals to replace salt losses through sweat and saliva (Matthewman and Dijkman, 1993).

Energy

The increased energy demand is the most obvious nutritional implication of work. It appears also that work increases the maintenance energy requirements of oxen. Experimental evidence of the additional cost of maintenance in working oxen was given by Lawrence, Buck and Campbell (1989) who found that resting metabolic rate of oxen fed below maintenance and working 6 h/day was on average 8% higher for 16 h after work than on days when they were idle. This effect was not seen in well fed animals. Furthermore Lawrence, Sosa and Campbell (1989) worked oxen at different rate and extrapolated the underlying resting rate back to 'zero work'. They found that the underlying resting rate during work was about 26% higher than the resting rate during the same time of the day on non-working days. The combined effect of these two increases means a 10% increase in the energy cost for maintenance of oxen during working days.

In the past, before the advent of modern portable gas analysers, the energy used for work was difficult to determine in the field. The energy costs of the different activities occurring during work were determined under laboratory conditions using treadmills. Values obtained were extrapolated to animals working in the field. Lawrence (1985) used the ME system to predict the energy requirements of draught animals. He developed a factorial method to estimate the extra energy needed for work. The net energy (NE) used for work is estimated as follows:

energy used for work = energy for walking
+ energy for carrying loads
+ energy for pulling loads
+ energy for walking uphill

This formula is quantitatively expressed as:

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

where E = extra energy used for work (kJ)

F = distance travelled (km)
M = LW (kg)
L = load carried (kg)
W = work done whilst pulling loads (kJ)
H = distance moved vertically upwards (km)
A = energy used to move 1 kg of body weight 1 m horizontally (J)
B = energy used to move 1 kg of applied load 1 m horizontally (J)
C = efficiency of doing mechanical work (work done / energy used)
D = efficiency of raising body weight (work done raising body weight / energy used).

Measurement of the two weights M and L is easy. F and W can be measured throughout the working day using the ergometer, an instrument designed at the CTVM (Lawrence and Pearson, 1985) to measure work output, distance travelled and time spent working. Factors A, B, C and D have been established under laboratory conditions and published values for cattle used in the factorial formula are shown in Table 2. The derivation of the ME needs for work from the NE needs computed from this formula requires further assumption regarding the efficiency of utilisation of ME for work. Lawrence (1985) assumes that the heat increment associated with work should be the same as that for maintenance since, in both cases, it is produced mainly as a result of converting the ME in the diet to the correct form for fuelling muscle tissue, albeit at a much greater rate in the working than in the non-working animal. Lawrence and Becker (1994) stress the need for more experimental work on this topic because work and maintenance are often the two most quantitatively important energy expenditures of draught animals and relatively small differences in efficiency of utilisation of ME would result in large differences in total energy requirements. The efficiency of utilisation of ME can also be affected by training (Teleni and Hogan, 1989). These authors found that a trained buffalo used ME more efficiently (approximately 6%) than its untrained counterpart.

Lawrence and Stibbards (1990) pointed out two major drawbacks in the application of the factorial method for the estimation of the extra energy used for work in animals working in the field. The animals may be working under climatic conditions that are different from those under which the factors for the equation were determined. Furthermore the energy cost of walking which contributes over 50% of the total energy cost of working is likely to be influenced by the nature and the slope of the ground on which the animals walk.

Table 2.
Published values for energy expenditure for walking and carrying in draught cattle and for the efficiency of doing work.

Activity	Mean energy expenditure	Animals	Reference
Walking (J/m/ kg LW)	1.9 2.0 2.1	Cattle (*Bos taurus*) Cattle (*Bos taurus*) Brahman cattle	Brody (1945) Ribiero et al. (1977) Lawrence & Stibbards (1990)
Carrying loads (J/kg carried)	2.6	Brahman cattle	Lawrence & Stibbards (1990)
Efficiency of doing work pulling (kJ work done / kJ energy used)	0.30	Brahman cattle	Lawrence & Stibbards (1990)
Efficiency of doing work raising body weight (work done/energy used)	0.36 0.35	Brahman cattle and Brahman × Friesian cattle	Thomas & Pearson (1986) ARC(1980)

Despite the limitations of the factorial method it remains a practical method for the estimation of the energy cost of work in the field. Its wider application in different farming systems requires that more investigation be carried out on the energy cost of walking under various ground conditions and the amount of work performed by oxen.

Lawrence and Becker (1994) proposed an alternative method of estimating the energy requirements of draught oxen in situations where the factorial method may not apply because the information on work output and distance travelled are not available. They formulated an equation that calculates the energy expenditure (multiple of maintenance) as: $\mathbf{1.1 + (0.219\times t^{0.89}) \times (0.1\times ME)^{-0.2}}$

where t = time spent working and ME = the metabolisable energy content of the diet given. They based this equation on the observed variations of the energy expenditure during a working day and on the fact that the energy expenditure by oxen during the working day is higher when the quality of the diet is higher. The increased basal metabolic rate of oxen due to work on working days is also taken into account in the prediction of energy expenditure using this method. The application of this method to an ox gave the estimates of the 24 h energy expenditure in relation to time worked and quality of the diet shown in Table 3.

The predicted range of energy expenditure as a multiple of maintenance agrees with values reported by Pearson and Lawrence (1992) and Pearson (1989). This method would be a convenient way of predicting the energy requirements of draught oxen in a farming system. However the required values of the ME of feeds and the patterns of variations of work output during a working a day are not always known, but they can be easily measured.

Table 3.

Energy expenditure (multiple of maintenance) calculated as:

$1.1+(0.219\times t^{0.89})\times(0.1\times \mathrm{ME})^{-0.2}$ (Lawrence and Becker, 1994).

ME MJ/kg in diet	5.0	5.5	6	6.5	7	7.5	8.0	8.5	9.0	9.5	10.0
Work time t (h)											
0.5	1.14	1.14	1.15	1.15	1.16	1.16	1.17	1.18	1.18	1.19	1.19
1	1.17	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.28
1.5	1.19	1.21	1.23	1.24	1.26	1.27	1.29	1.30	1.32	1.34	1.35
2	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42
2.5	1.25	1.27	1.30	1.32	1.35	1.37	1.40	1.42	1.45	1.47	1.50
3	1.27	1.30	1.33	1.36	1.39	1.42	1.45	1.48	1.51	1.54	1.57
3.5	1.30	1.33	1.37	1.40	1.43	1.47	1.50	1.53	1.57	1.60	1.63
4	1.33	1.36	1.40	1.44	1.48	1.51	1.55	1.59	1.63	1.66	1.70
4.5	1.35	1.39	1.43	1.48	1.52	1.56	1.60	1.64	1.68	1.73	1.77
5	1.38	1.42	1.47	1.52	1.56	1.60	1.65	1.70	1.74	1.79	1.83
5.5	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90

2.2.4. Monitoring of work output

Accurate measurement of work performance is a prerequisite for the estimation of the energy expenditure and therefore of the energy requirements of working animals. Work output is a function of draught force exerted and distance travelled. Draught force is therefore a fundamental measurement to be taken from draught animals. Dynamometers were traditionally used to measure draught force. These instruments are mounted between the animal and the load and give draught force averaged over a short time (2-5 s) after several hundred separate measurements are taken at equal time intervals. The time based average draught force (TADF) obtained from dynamometers is useful for engineers to assess the stress experienced by harnesses and machinery (Lawrence and Pearson, 1985). However errors can be attached to the work output of draught animals calculated with TADF because draught force varies continuously during work under field conditions. The integration of draught force with respect to distance (DADF) is a more appropriate way to calculate work output for feeding purposes (Lawrence and Pearson, 1985). These authors took simultaneous measurements TADF and DADF using draught oxen performing work of different natures (steady, jerky and heavy). They concluded that in the case of low, even loads pulled by large, well-trained oxen, the difference between TADF and DADF may be negligible. However, in the case of large, jerky loads pulled by small or inexperienced animals, TADF can create errors that are both large and unpredictable. The need to make reliable measurements of draught force for long periods, for instance during a whole working day, led to the development of two instruments.

Peter Lawrence, at the CTVM, designed the 'ergometer', an instrument that allows long term determination of work output using DADF. The ergometer is designed specifically for measuring the distance travelled, work output, draught force, speed and elapsed working time (EWT) of single or paired draught animals. It consists of three parts: an odometer, a load cell and an integrate and display (ID) unit (CTVM, 1987).

The odometer consists of:

(a) a shaft coupled with a cross-piece via a universal joint,

(b) a pair of forks to support parts (c) and (d). The forks may be rotated in relation to part (a) so the odometer may be attached to vertical or horizontal parts of the implement,

(c) a rear bicycle wheel onto which is screwed a 60 tooth timing pulley,

(d) the distance detector consisting of a flat, sealed aluminium disc containing a wheel with 60 slots round the perimeter that pass through an infra-red detector. The gearing system is such that 360 slots pass through the detector per revolution of the bicycle wheel.

The Novatech F241 (Novatech Instruments, UK) load cell with 8 mm rod ends dust seals and mechanical overload protection is recommended for use with the ergometer. The load cell operates over a range of draught forces varying between 0 and 3000 N and is positioned so that all the draught force exerted is transmitted through it.

The integrate and display (ID) unit provides and regulates the power input to the load cell and the odometer and processes signals from them. The ID unit can function in 4 modes. Mode 1 that is the normal operating mode produces 3 outputs: work (kJ), distance (m) and elapsed working time (s). Mode 2 is similar to mode 1 except that work is displayed in kJ×100. This mode is used for light loads (<200N) or short readings. Mode 3 is only used for the calibration of the ergometer. In mode 4, the ergometer produces repeat measurements of draught force (N), more specifically DADF, and reciprocal speed (CTVM, 1987).

The Silsoe Research Institute, Overseas Division, Silsoe, Bedford designed an instrumentation system to monitor the performance of draught animals and implements while work is in progress. It is made up of three sub-systems: the sensors, the signal conditioning circuit and a microcomputer that acts as the logger/monitor. This system enables the monitoring of three mechanical variables (draught force, draught angle and distance travelled) and four physiological variables (heart rate, breathing rate, body temperature and stepping rate) during work (O'Neill, 1989). A strain-gauge load cell sensor placed between yoke and implement measures draught force whereas the draught angle is measured by a potentiometric inclinometer suspended below the load cell. Distance is measured using either a microwave radar devise or a trailing wheel. Heart rate is measured by detecting the change in infrared absorbance of the ear as blood pulses through. Breathing rate is determined by sensing air movement through a tube fixed near one of the animal's nostril. Two thermistors are inserted in the tube, at each side of a heater which yield differential temperature signals dependent of the direction of the air flow during inhalation and exhalation. A rectal probe with an embedded thermistor measures body temperature. Stepping rate is measured by an accelerometer strapped to one of the animal's lower foreleg (O'Neill, 1989).

2.2.5. Measurement of energy expenditure by draught oxen

The development of calorimetry, the science that studies the heat production in animals, allowed the measurement of the energy expenditure of humans and a number of farm livestock. Except for horses (Brody, 1945), the heat production of draught animals was seldom investigated because of difficulties in the application of calorimetric techniques in the field. Most studies that investigated the energy expenditure of draught animals were conducted in laboratories with the subsequent extrapolation of results for animals working in the field. As a result, empirical knowledge and farmer's experience formed the main basis of the feeding of draught animals (Pearson and Dijkman, 1994). Recent adaptations of portable gas analysers to draught animals have enabled the energy costs of the different activities that occur during work to be established.

Direct calorimetry measures heat dissipated by the body through radiation, convection and conduction whereas indirect calorimetry measures heat generated in the body (McLean and Tobin, 1987). Direct calorimetry has little application to draught oxen because the change in enthalpy of the air that is a measure of the body heat content is difficult to measure in free-ranging animals. Moreover the mechanical work done by the animal cannot be accounted for in the heat exchange budget Therefore the determination of the energy expenditure in working animals has been based on indirect calorimetry (Lawrence and Pearson, 1985).

Principles of indirect calorimetry

Two assumptions are fundamental to the measurement of metabolic heat production by indirect calorimetry. First, it is assumed that the end result of all biochemical reactions that occur in the body amounts effectively to the combustion of the three substances- carbohydrates, fat and protein. Second, it is assumed for each of these substances, when it is oxidised in the body, there are fixed ratios between the quantities of oxygen (O_2) consumed, carbon dioxide (CO_2) produced and heat produced (McLean and Tobin, 1987). The heat produced by an animal can be accurately estimated by measuring its gaseous exchange if the specific respiratory quotient of carbohydrate, fat and protein, that is the volumetric ratio of CO_2 produced to oxygen consumed, and their heats of production per l of O_2 consumed are known.

In the past, the heat of combustion of carbohydrates, fat and protein, the oxygen consumed during combustion of these substances and the ratio of heat produced to oxygen consumed were determined from the results of combustion of the materials in a bomb calorimetry. For instance the heat of combustion of carbohydrates in the diet of the animal varies between 15.64 kJ/g for monosaccharides such as glucose to 17.50 kJ/g for polysaccharides such as glycogen. The respective values for the heat produced per litre of oxygen consumed are 20.95 and 21.11 kJ/l O_2. The respiratory quotient (RQ) is equal to 1 (Mclean and Tobin, 1987). Animal fats are very variable in their composition, but the average heat produced per litre of oxygen for most animal fats is equal to 19.75 kJ/l O_2 and the average respiratory quotient is equal to 0.7. Proteins are not completely oxidised to CO_2 and water. Nitrogen is converted to urea and excreted into urine in mammals. The amount of protein metabolised and the amount of O_2 consumed and CO_2 produced in association with the protein can be estimated from the measurement of quantity of urinary nitrogen. The estimation of heat production in ruminants should take into account methane (CH_4) formation in the rumen using energy that would otherwise be lost as heat. Each litre of methane produced by anaerobic processes represent a loss of 39.4 kJ of energy (McLean and Tobin, 1987).

New methods of the prediction of heat production of animals are based on algebraic analysis using a simple linear equation. The application of caloric factors drawn up by Brouwer (1965) for farm animals allows the estimation of energy metabolism from gaseous exchange using the following equation (Lawrence and Pearson,1989; Blaxter, 1989):

$$H = 16.2C + 5.1P - 6.5U - 2.0M$$

where

H = heat produced (kJ);

C = O_2 consumption (std l);

P = CO_2 production (std l);

U = urinary nitrogen (g);

M = CH_4 production (std l)

The relative contribution of the various factors are 77.3, 23.9, 0.7 and 0.5 % for O_2, CO_2, CH_4 and urinary nitrogen, respectively when this equation is applied to calculate the 24-h energy consumption of a 725 kg ox fed at maintenance on high carbohydrate, low protein diet (Lawrence *et al.* 1991). Because CH_4 and urinary nitrogen have quantitatively little influence, they are often omitted. Moreover the estimation of heat production can be further simplified. Since O_2 accounts for 77.0 % of the total value, O_2 alone has been used to predict heat production. The estimation of heat production using O_2 consumption alone makes the assumption that RQ is equal to 1. However, RQ can vary from 1.3 when fat is synthesised from carbohydrates to 0.7 when fat is oxidised. Lawrence *et al.* (1991) report that RQ for adult ruminants fed around maintenance level is in the range of 0.8-1.0. If a value of 0.9 for RQ is adopted the equation for the prediction of heat production becomes: $H = 20.7 \times VO_2$, where VO_2 is the volume of oxygen consumed.

Measurement of gaseous exchange in draught oxen

The instruments devised to measure gaseous exchange in animals, in general, work on four principles (Mclean and Tobin, 1987). First, in 'closed circuit' instruments air is passed within a closed system whether a chamber or a mask. Carbon dioxide and water produced are absorbed by suitable absorbents and oxygen consumption by the animals is measured as it is replaced. Second, the 'confinement' method monitors the changes in gas concentrations in a sealed chamber. Third, in the 'total collection' method, all the expired air is collected and total volume and chemical composition is determined. Fourth, in the 'open circuit' system atmospheric air of known composition is passed through the system. Its rate of flow is determined and the increase in its CO_2 content and decrease in O_2 content are measured. The Classic 'open circuit' systems have been successfully applied to draught animals in chambers or wearing a face mask (Brody, 1945; Lawrence and Stibbards, 1990). Field conditions such ground condition and gradients have been simulated by working animals on a treadmill or a circular race (Lawrence *et al.*, 1991). Major drawbacks of this technique, concerning its use for draught animals, are that the apparatuses for gas analysis are not portable and it does not allow the gaseous exchange of animals performing common agricultural operations to be measured. To overcome these problems and to enable the measurement of gaseous exchange of free-ranging animals portable gas analysers have been devised and are most favoured for use with draught animals in the field.

Methods and examples of portable 'breath by breath' analysers

In these instruments the experimental animals wear a face mask fitted with an inlet and outlet valves and a flowmeter that measures the volume of each breath. The method of sampling of the expired air, the type of flowmeter used and the method of gas analysis determine the differences in the designs of these instruments. In some instruments a constant proportion of the expired air is sampled at each breath. The sample is stored in suitable bag or container for subsequent laboratory analysis. The difference between the gas concentrations of the inspired air and the sample is multiplied by the total flow to give total gaseous exchange. Major disadvantages of this system are that the apparatus should be used near laboratory facilities and that changes in metabolic rate during the experiment cannot be monitored unless many samples are taken (Lawrence *et al.,* 1991). In other systems the gas concentration of each breath is directly analysed. The volume flow rate is analysed either by a turbine flowmeter or a pneumotachograph (McLean and Tobin, 1987). The latter has the advantage of an unrestricted airflow but its linearity tends to be affected during use because sedimentation of saliva and dust particles creates turbulence in the air flow reducing its reliability (Dijkman, 1993). Oxygen concentration is measured with oxygen electrodes or polarographic cells (McLean and Tobin, 1987).

Many 'breath by breath' systems have been developed. Hornicke, *et al.* (1974) developed an apparatus for use in horses. Air flow was measured by a strain gauge pneumotachograph and O_2 concentrations were measured by a fast polarographic O_2 electrode. Clar (1991) made an apparatus with a mask fitted with two inlet valves and one outlet valve. A constant proportion of the expired air is sampled from a gas meter by a pump and stored in an aliquot collection bag and analysed later for O_2 and CO_2 with a blood gas analysis system. In the instrument developed by Howell and O'Neill (1990) the flow rate is measured by a heated pneumotachograph avoiding therefore the problem of condensation of water vapour from the animal's breath. These instruments have had only limited use in draught animals because of major technical problems and drawbacks pointed out by Lawrence *et al.* (1991) and Dijkman (1993). Not only are they expensive but also they are difficult to adapt to animals of different sizes. Moreover the problems of storage of samples meant that the apparatus could only be used near a laboratory. To avoid these problems Lawrence and Dijkman at the CTVM modified the Oxylog (P.K. Morgan Ltd, Kent, UK), a portable breath by breath analyser originally designed for humans, to suit draught animals.

The Oxylog

The Oxylog (P.K. Morgan Ltd, Kent, UK) is a portable instrument designed to measure the O_2 consumption of an ambulatory subject. It measures ventilation volume and determines total O_2 consumption after corrections for atmospheric temperature, pressure and humidity. The apparatus is composed of an airtight face mask with inlet and outlet valves and an analysis and recording unit. The inlet side of the face mask is fitted with an inspiratory valve in which is incorporated a turbine flowmeter and a thermistor. On the outlet side of the face mask a flexible tube takes the expired air into the analysis and reading unit after the expired air was dried in a tube containing anhydrous calcium sulphate. A double piston pump takes samples of mixed expired air for analysis by a polarographic O_2 sensor. A second sensor measures atmospheric O_2 concentration. The Oxylog was modified to suit measurement of O_2 uptake in draught animals (Lawrence *et al.,* 1991). The turbine flowmeter was scaled up and the number of inlet and outlet valves were increased from 1 to 3 and were placed in a larger tube to increase their capacity. A mask was designed to fit oxen which incorporated a saliva trap and allowed the ox to be guided by a halter or by a nose ring. The basic frame of the mask is made out of plywood and is of a geometrically simple shape. It is sealed by a cuff of 1 mm thick natural rubber. Advantages of this type of mask are that it easily made, cheap and fits animals of different sizes. Major inconveniences of the Oxylog include the reluctance of some animals to wear the face mask, but this can be overcome by the selection of appropriate animals and their adequate training (Lawrence *et al.,* 1991).

Other methods of measurement of gaseous exchange in oxen

The metabolic rate monitor (MRM) devised by Webb and Troutman (1970) is a portable flow-through system which allows the continuous measurement of O_2 consumption in humans. Important features of this instrument are that the speed of the pump which draws air from the mask is controlled by a feedback loop made active by two polarographic O_2 sensors measuring respectively in and out airstreams.

The loop adjusts the speed of the pump so that the difference in O_2 concentration is maintained at a fixed value. The mask does not need to be airtight because of the negative pressure in it. Although the absence of valves avoids the problem that the wearing of the mask may interfere with the animal breathing, wind blowing may influence the accuracy of the instrument in the field (Dijkman, 1993). Despite its simplicity this instrument has not been widely used.

The CO_2 entry rate method involves the infusion of $NaH^{14}CO_3$ at a constant rate into an animal and the observation of the specific activity of CO_2 in the body. After the infused material has reached an equilibrium with the body pool of CO_2 , the CO_2 entry rate is calculated from the ratio of the infused radioactivity to the specific activity of CO_2 in the body (Young, 1970). This technique has been applied to grazing cattle (Young, 1970). This method may be inconvenient for the measurement of energy expenditure in working animals because their metabolic rates change faster than turnover rate of the CO_2 pool. The precision of the method has been improved so that an overestimate of only 2-4% was found between estimates of CO_2 production with those determined in a respiration chamber (Whitelaw, Brockway and Reid, 1972). The necessity of continuous and precise infusion of the labelled bicarbonate solution is a major inconveneince of this method (*Lawrence et al.*, 1991).

The double or triple labelled water methods of estimating energy expenditures are based on the principle that there is an isotopic equilibrium, due to activity of carbonic anhydrase, between the O_2 of CO_2 and that of water (Blaxter, 1989). Deuterium (^2H) is removed from the body almost entirely as $^2H_20$, $^{18}O_2$ however, is also lost as respiratory CO_2 and therefore the turnover rate of O_2 in the body is greater. The difference in the two rates of decrease multiplied by the volume of the total body H_2O will give the rate of loss of CO_2. The procedure consists of giving an oral dose of labelled water and measurement of its concentration during the ensuing days (Young, 1970). The prohibitive cost of the labelled water limits the utilisation of this method with draught oxen (Lawrence *et al.*, 1991).

2.3. Experimental work: The energy cost of working on sandy soils

2.3.1. Material and methods

Animals and feeding

This experiment was conducted from October to November 1994 at the ICRISAT Sahelian Centre in Niger. Table 4 lists the age, weight and sex of the seven Diali (*Bos indicus)* cattle used in this experiment. These animals had been previously trained and used for work and proved suitable for experimental purposes. The animals grazed 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

Instrumentation

The modified Oxylog (Lawrence *et al.*, 1991) was used to monitor O_2 consumption. Work output, distance travelled and time spent working were measured using the CTVM ergometer (Lawrence and Pearson, 1985). The Oxylog and the ID unit of the ergometer were placed one in each pocket of a two-pocket backpack harnessed on the back of one animal in the team.

Adaptation

The animals used in this experiment were already well trained for work. Further training was however necessary so that they became accustomed to the instruments being attached to them. 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.

Table 4.

Age, weight and sex of cattle used in the experiment on energy expenditure.

Animal number	Sex	Weight (kg)	Age (years)
4	Entire male	341	6.5
9	Castrated male	525	7
10	Entire male	282	5
13	Entire male	294	5
16	Entire male	354	5
21	Entire male	365	5
24	Entire male	364	5

Work routine

Two main 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 ground 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:

The animals

- stood for 15 min in the shade,
- walked unloaded for 15 min on unploughed soils,
- walked unloaded for 15 min on previously ploughed soils and
- ploughed for 20 min.

For each activity animals worked for 5 min to reach a steady state metabolic rate before measurements were taken. Data were collected using a display panel connected to the Oxylog. During the walking sessions, the odometer was wheeled behind the animal by a worker 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:

The animals

- stood for 15 min,
- walked unloaded around a laterite flat circuit of 1000 m,
- pulled a cart loaded with 300 kg around the circuit,
- pulled a cart loaded with 600 kg around the circuit and
- pulled a cart loaded with 900 kg around the circuit.

Computation of the energy costs of standing, walking and working

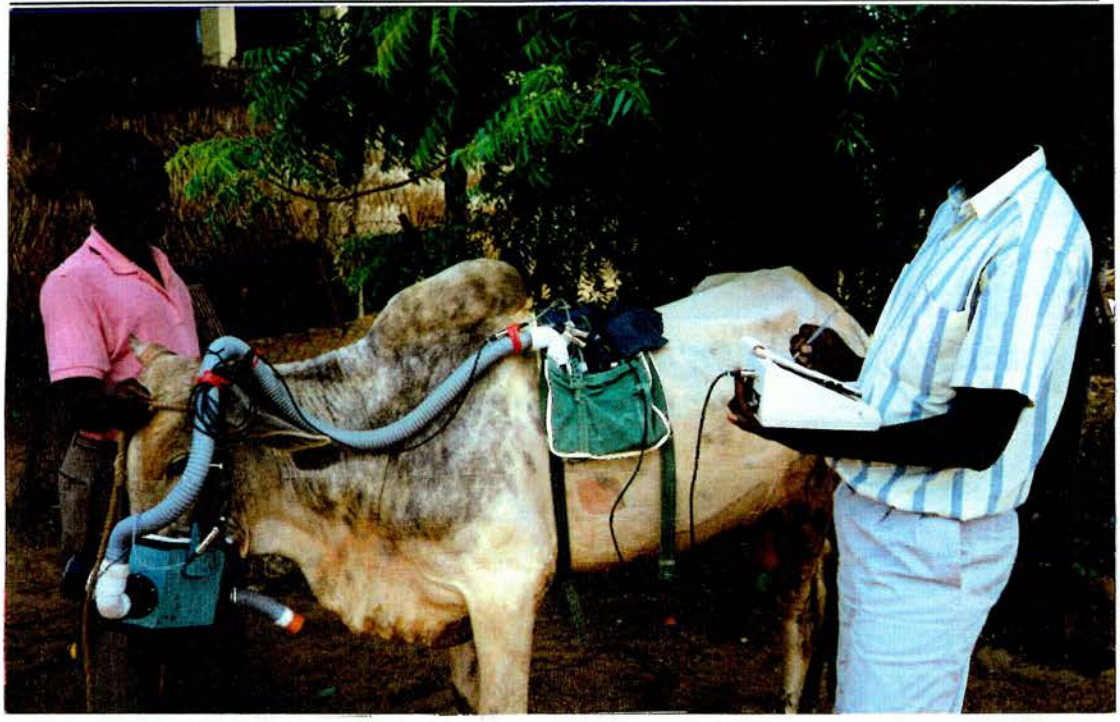
The measurement of heat production was derived from O_2 consumption assuming 20.7 kJ per litre of O_2 consumed. The value of 20.7 kJ/l O_2 was used assuming a relation between heat production to O_2 consumption alone (section 2.5.1, Lawrence *et al.* 1991).

The standing metabolic rate (SMR) was defined as:

SMR (kJ/kgLW$^{0.75}$) = [average heat production per min (kJ/min) while oxen were standing still × 1440 min / metabolic live weight (kgLW$^{0.75}$)]

The energy cost of walking E_w was defined as:

E_w (J/m walked per kg LW) = [energy used while walking - energy used while standing still]/ [distance walked (m) × LW (kg)].



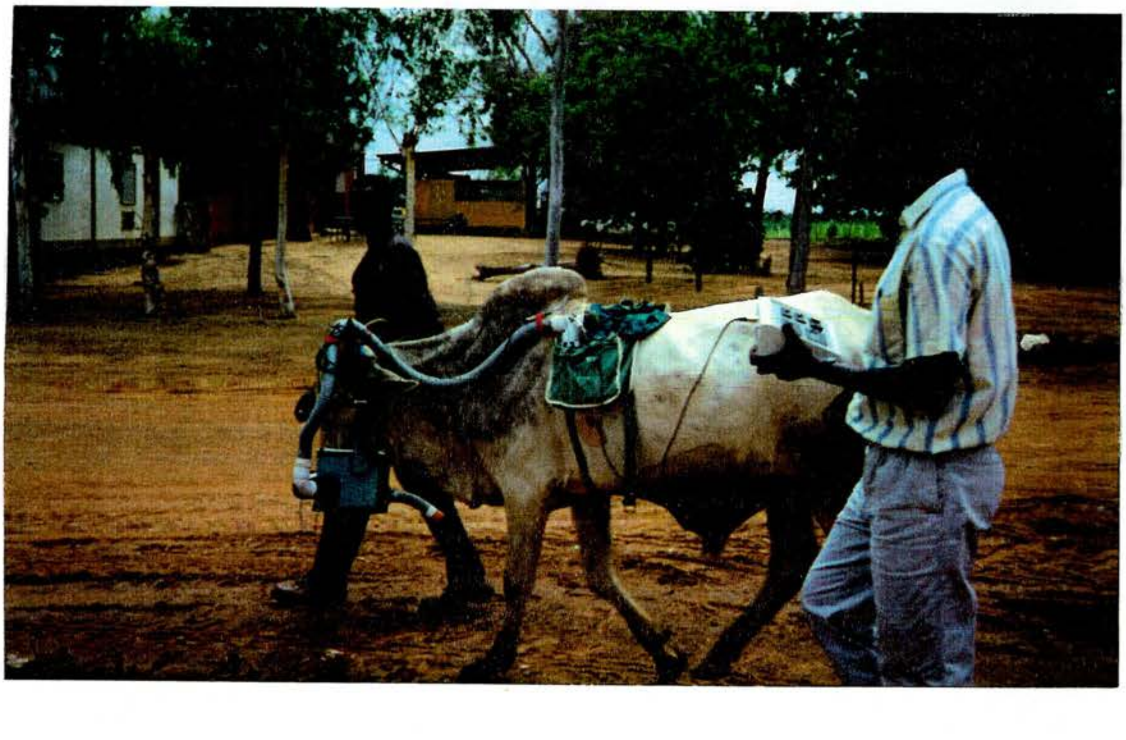


Plate 1.

Measurement of the standing metabolic rate (top picture) and the energy cost of walking (Bottom picture) of an ox in Niger using an Oxylog

The energy cost of doing work was defined as an efficiency factor (E_f) where: efficiency (E_f) = [work done (kJ) / (energy expended when loaded (kJ) - energy expended (kJ) to walk the same distance at the same speed but unloaded)] (Lawrence and Stibbards, 1990).

The information obtained from this experiment was incorporated in the factorial formulae (Lawrence and Stibbard, 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 average walking speed of 0.92 m/s found in this study. This load would be equivalent to 16% of the live weight of animals in the pair weighing each 300 kg, 12% for animals with a live weight of 400 kg and 10% for animals with a live weight of 500 kg. Maintenance energy requirements (EM) were estimated as: $EM = 1.15(0.53(LW/1.08)^{0.67})$ (AFRC, 1993). The energy cost for maintenance was increased by 10% to account for firstly the higher metabolic rate after work as compared to non-working days (Lawrence, Buck and Campbell, 1989) and secondly 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 and E_f were subjected to analysis of variance. The statistical model used for E_w and E_f included the main effects of the animal and the ground surface. The animal LW and walking speed were included as covariates. 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.

2.3.2. Results

Standing metabolic rate

Mean daily energy cost of standing was 487 (±10.6) kJ/kg $LW^{0.75}$. O_2 uptake averaged 1.35 (±0.029) l/min, 0.016 (±0.00032) l/min/kg $LW^{0.75}$ and 0.0038 (±0.000082) l/min/kg LW. On the basis of these results the total heat production of a bull of an average weight of 367 kg, as in this experiment, would be 40.83 MJ /day.

Energy cost of walking

Table 5 shows the energy cost of walking (E_w) and the walking speed on unploughed and ploughed sandy soils and on laterite tracks. Ground surface affected E_w and walking speed ($P<0.01$). Average energy cost of walking by the oxen walking in teams two for work was 1.59 (±0.069), 2.15 (±0.084) and 1.00 (±0.10) J/m/kg LW on unploughed, ploughed sandy soils and on laterite tracks, respectively. 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. The regression of E_w on LW was significant. The heavier the animal the higher was the energy cost of walking. Each extra kg of LW 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 5).

Energy cost of working

Table 6 shows the efficiency of ploughing and carting, the average draught force exerted and walking speed. The average draught force required to plough sandy soils by ox teams in this experiment was 978 (± 70) N. Ploughing was performed using a mouldboard plough at an average depth ranging from 12.9 (±0.68) to 17.1 (±0.73) cm. Soil moisture content was 2.2, 2.7, 2.9 and 3.0% at 0-5, 5-10, 10-15 and 15-20 cm of depth, respectively. Teams worked at an average speed of

0.92 (±0.044) m/s. The efficiency of ploughing was 0.32 (± 0.056). Average draught forces during carting were 386 (±5.7), 486 (±6.5) and 574 (±6.4) N for the 300, 600 and 900-kg loads respectively. The type of activity, LW, draught force and walking speed did not influence working efficiency. 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.

Table 5.
Mean ± s.e. energy costs of walking and walking speed of oxen walking on ploughed soils, unploughed soils and on laterite tracks.

Ground surface	No. of animals	No. of observ.	Energy cost of walking: (J/m/kg)	Walking speed (m/s)
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 ± 0.10	1.26_b ± 0.033
Significance			*	**

* $P< 0.05$; ** $P<0.01$; s.e.: standard error of the mean; Values in the same column with different subscripts are significantly different.

Table 6.
Mean ± s.e. draught force, walking speed and efficiency of ploughing and of carting by oxen working in pairs.

Activity	No. of animals	n	Efficiency	Draught force (N)	Walking speed (m/s)
Ploughing	5	19	0.32 ± 0.056	978 ± 70	0.92 ± 0.044
Carting:					
load= 300 kg	5	18	0.37 ± 0.029	362 ± 37	1.25 ± 0.020
load= 600 kg	5	17	0.35 ± 0.036	478 ± 45	1.25 ± 0.020
load= 900 kg	5	16	0.34 ± 0.026	548 ± 32	1.22 ± 0.021

Quantification of the extra energy requirements for ploughing

Table 7 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 the live weight of the animal and the number of hours work is done, the extra net energy expended for ploughing varies between 0.13 to 0.92 times the energy cost for maintenance.

2.3.3. Discussion

Standing metabolic rate

In this experiment the standing metabolic rate (SMR) averaged 487 (±10.6) kJ/kg $LW^{0.75}$. O_2 uptake during resting periods was 0.027 l/min/kg $LW^{0.75}$ for crossbred dairy cows in Ethiopia (Zerbini, Gemeda, O'Neill, Howell and Schroter, 1992). This translates to a SMR of 637 kJ/kg $LW^{0.75}$ using the rate of 20.7 kJ per litre of O_2 consumed. Using Bunaji zebu bulls, average LW 378 kg, in Nigeria, Dijkman (1993) found O_2 consumption during resting periods of 0.022 l/min/kg $LW^{0.73}$ that is equivalent to a SMR of 582.5 kJ/kg $LW^{0.75}$. Becker, Rometsch, Susenbeth, Roser and Lawrence (1993) measured a SMR of 410 kJ/kg $LW^{0.75}$ for zebu oxen in Niger. Differences in these results may be attributed to differences in breeds used and in the measurement techniques of O_2 uptake adopted in different experiments. 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. As pointed out by Lawrence, Sosa and Campbell (1989), the rate of energy expenditure of well trained oxen fed at maintenance and standing still between bouts of work is on average proportionally 0.26 higher than the average rate during the same time of the day when the oxen were in a respiration chamber. Increasing the SMR found in this experiment to simulate SMR between bouts of work and averaging this value with that found in this experiment gives a SMR of 549 kJ/kg $LW^{0.75}$ that is closer to the resting metabolic rate of 582 kJ/kg $LW^{0.75}$ found

Table 7. Live weight (LW, kg), draught force for ploughing as a proportion of live weight (DF/LW, %), 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).

LW (kg)	DF/ LW (%)	EM (MJ)	Ploughing for 1 h/day		Ploughing for 2 h/day		Ploughing for 3 h/day		Ploughing for 4 h/day		Ploughing for 5 h/day		Ploughing for 6 h/day	
			A	B	A	B	A	B	A	B	A	B	A	B
300	16	34.7	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	12	43.1	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	10	50.9	0.11	0.13	0.21	0.26	0.32	0.39	0.43	0.52	0.44	0.65	0.64	0.78

by Dijkman (1993). The high value of 637 kJ/kg $LW^{0.75}$ reported by Zerbini *et al* (1992) may be related to the *Bos taurus* × *Bos indicus* crossbred dairy cows they used. These animals may have a higher metabolic rate than the *Bos indicus* breeds used by Dijkman (1993), Becker *et al.* (1993) or the *Bos indicus* breed used in this experiment. In a study conducted 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).

Energy cost of walking

In this study the E_w was determined on three types of ground surface: unploughed and ploughed sandy soils and laterite tracks. The significant effect of ground surface on the energy cost of walking agrees with results reported by Dijkman (1993). He measured E_w on upland soils and on valley soils with a high clay content in Nigeria. The measurements were made at two soil moisture contents (dry or wet). The E_w of 1.59 J/m/kg LW on unploughed sandy soils found in this experiment is close to the E_w of 1.47 J/m/kg LW on unploughed upland and the E_w of 1.76 on unploughed dry valley bottom soils found by Dijkman (1993) in Nigeria. However, the E_w on upland soils or on valley bottom soils were higher than the E_w on sandy soils reported here when these soils were ploughed, either wet or dry. Differences in the clay and moisture contents between sandy soils and upland or valley bottom soils and therefore the ease of walking on them may explain differences in the E_w between these two studies.

The energy costs of walking found in this study, with the exception of the cost of walking on ploughed soils, are lower than values determined on treadmills with firm, even surfaces. Common values for the E_w used for cattle in the determination of energy requirements are 2.0 J/m/kg (ARC, 1980) and 1.9 J/m/kg (Brody, 1945). Lawrence and Stibbards (1990) also reported an E_w of 2.09 J/m/kg for Brahman cattle and swamp buffalo walking on a treadmill. The E_w found in this study is of the same order of values of E_w found in field studies. For instance, 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 is similar to the E_w on laterite tracks found in this study. Discrepancies between laboratory and field values of E_w can be explained by the artificial circumstances occurring in laboratory settings, which may cause increases in metabolic rate of animals under study (Dijkman, 1993). When oxen walk in the field they travel at their own speed which may be more comfortable than when they are forced to walk at a certain speed on a moving treadmill surface. This illustrates the importance of conducting this type of study in the field, if more accurate values of heat production are to be established for draught animals.

In this experiment the energy cost of walking was independent of the walking speed. As pointed out by Brody (1945), the energy cost of walking increases as speed decreases if the rest-maintenance component of the cost in included. However, if the maintenance cost is excluded from the total energy cost, as 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 not influenced by speed any more. Taking into account the above considerations, the prediction of the energy cost of walking using walking speed as suggested by Dijkman (1993) may not be valid. He did not report estimates of the extent and the significance of the association between the energy cost of walking and walking speed in his study.

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 of 0.32 is consistent with average efficiencies of pulling loads reported by Lawrence and Stibbards (1990). These results are also in agreement with values reported by Dijkman (1993). He found an average efficiency of 0.30 to 0.31 for oxen ploughing upland and valley bottom soils in Nigeria. Walking speed did not also affect the efficiency of doing work. This again agrees with the observations of Lawrence and Stibbards (1990). They did not find any significant effect of speed of walking on efficiency when animals were walking at a comfortable speed.

These results have important implications for the determination of energy requirements of oxen working on sandy soils. The factorial method for estimating the energy cost of working (Lawrence and Stibbards, 1990) can be applied to oxen working on sandy soils on the basis that the efficiencies of pulling loads are similar to those reported in the literature. However, the energy cost of walking to be included in the factorial formula should be adjusted according to the findings of this study. First, the lead animal walking on soil already ploughed will spend 0.35 more energy for walking than the animal walking on the unploughed soil. Second, carting is commonly performed on firm grounds. Therefore the application of the E_w of 2 J/m/kg (Lawrence and Stibbards, 1990) would overestimate the energy cost of working. During carting a value of about 1.00 J/m/kg would be more appropriate to oxen in semi-arid areas carting on firm ground.

In this experiment a mouldboard plough was used for the ploughing trial. The same implement could be used for direct ridging on untilled sandy soils. 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, Table 1). 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 could be applied to direct ridging of sandy soils using a mouldboard plough. Results from the present experiment showed that an average draught force of

978 N would be required to till at an average depth of 15 cm. This means that a team totalling a minimum LW of about 890 kg would be needed for ploughing, assuming oxen can sustain a draught force equivalent to 11 kgf/100 kg of their liveweight over a working day.

The application of the factorial method for estimating the extra net energy used for work using values of the energy cost of walking and the efficiency of doing work found in this study, yielded values of the extra energy for work ranging from 0.13 to 0.92 times maintenance energy requirements depending on the number of hours worked and the live weight of the animals in the team. The extra net energy for work found in this study is in agreement with values reported by Mahardika *et al.* (1994). They estimated the energy expenditure of water Buffaloes pulling draught forces equivalent to 10 and 15% of the live weight of the animals for 3 hours. The energy expenditure of buffaloes was .42 and .48 times maintenance energy requirements for the 10% and 15% load, respectively. The extra energy cost for work found in this study is also within the range of values (0.74 - 0.78 times maintenance energy requirements) reported by Pearson (1989) for large and small cattle pulling carts for 5 hours/day. The estimated level of energy expenditure during 5 to 6 hours of ploughing sandy soils ranged between 0.54 for oxen weighing 500 kg to 0.92 for oxen weighing 300 kg. Again these values are in agreement with the optimum level of energy expenditure of 0.70 times maintenance energy requirements suggested by Lawrence (1985) for oxen working most of the week.

CHAPTER III

INTAKE AND DIGESTION OF FEED BY DRAUGHT OXEN IN SEMI-ARID AREAS OF AFRICA

3.1. Introduction

Ideally, draught oxen must consume sufficient feed before and during the cropping season so that they can start work with a reasonable LW and also accommodate the energy used for work. This is difficult to achieve. Beside the nutritional constraints imposed by the low quality and quantity of the feed at their disposal, draught animals have limited time available to eat and ruminate during working days (Pearson and Smith, 1994). High body temperatures, resulting from the increased metabolism during work and heat gains from high ambient temperatures found in semi-arid areas, causes heat stress in the working animal. Reduced gut motility and rumination are associated with heat stress (Collier and Beed, 1985) Hence, work, particularly at high ambient temperatures, may adversely affect intake (Collier and Beed, 1985). Work could, on the other hand, stimulate feed intake because of the oxidation of energy yielding-substrates and the need to compensate for the energy used during work. Furthermore, increased rumen temperature and better mixing of the rumen content resulting from exercise could have beneficial effects on feed digestibility. Previous studies that investigated the effect of work on intake and digestibility of feeds reported contrasting results. There is, therefore, a genuine need to elucidate the relationships between feed intake and the efficiency of utilisation of feeds and work performance. This information is required to identify appropriate feeding strategies for draught oxen in semi-arid areas where oxen are fed on cereal crop residues.

This chapter is intended to investigate the nutritional implications of work for draught oxen working under hot conditions found in semi-arid areas. First, the feeding systems for draught oxen in these areas are described. Second, the control of feed intake in ruminants and the nutritional constraints of draught oxen are reviewed. Finally this chapter gives details of and the results obtained from two experiments that were designed to investigate the relation between work and intake and digestion of feed by oxen working under high ambient temperatures and fed on crop residues. It was hypothesised that limited time to ruminate depresses intake in working oxen. However digestibility of feed could improve as a result of reduced intake and gastrointestinal transit time.

3.2. Literature review

3.2.1. Feeding systems for draught oxen in semi-arid areas

Feed resources

Naturally occurring grasses and legumes and cereal crops (millet, sorghum) residues form the basal diet for draught oxen throughout the year in semi-arid areas. Feed supplements fed to draught animals include concentrates from crops such as groundnut and cotton, cereal milling residues, groundnut and cowpea hay, tree leaves and fruits, urea and minerals. The seasonal variation in the availability and the quality and the spatial distribution of these feed resources together with the calendar of use of draught oxen during the year determine the feeding system for draught oxen in semi-arid areas.

Natural pastures

The productivity and the quality of natural pastures in semi-arid areas are determined by variations in the amount of rainfall between and within years. The distribution of rainfall within a year appears to be more determinant than the total amount of rainfall during the year (Hiernaux, Cissé and Diarra, 1983). The nutrient content of pasture forages, particularly the N content, is often singled out as the most important determinant of feed intake by cattle grazing natural pastures in semi-arid areas. The intake of forages was reduced markedly when their crude protein content was less than 7% (Van Soest, 1995; Osburn, 1974). Dicko (1983) monitored the feed intake of grazing cattle in the semi-arid areas of Mali. She found that intake of feed dry matter was associated with the protein content of the selected diet. Although the quality of vegetation is an important factor that influences feed intake in semi-arid areas, another main constraint to feed intake in these areas is also the limited availability of the consumable biomass (Schelcht, Sanghare and Becker, 1994). These authors monitored the protein content of the diet and the feed intake of fistulated cattle grazing natural pastures in the semi-arid areas of Mali. They concluded that zebu breeds in semi-arid areas have the ability to tolerate a significant increase in gastrointestinal fill. This enables higher intake of low quality feed in zebu breeds as compared to breeds in temperate zones. The standing biomass in pastures of semi-arid areas becomes limited as the dry season progresses because of the natural decay of the vegetation and losses caused by termites and fire as well as intensive grazing. This shortage of plant biomass is compounded by the fact that, in many parts of the semi-arid areas, increased demand for cropping lands due to high population growth has led to the encroachment of cropping areas into pasture lands. In such situations, draught animals resort to road sides, borders of cropped lands and marginal lands to secure their feed supply. In certain semi-arid zones such as the groundnut basin of Senegal, scarcity of grazing lands has caused a dramatic reduction in the cattle population and a shift to the use of cows for draught purposes (Lhoste, 1987).

Crop residues and agro-industrial by-products

Roughages from pearl millet (*Pennisetum thyphoides*) and sorghum (*Sorghum bicolor*) contribute considerably to the total feed available for livestock in semi-arid areas. Rice straw is also available in parts of the semi-arid areas where land development allows irrigated rice production. These feeds are the main sources of nutrient intake for cattle after harvest of the cereal grain. For instance, cattle spent 43% of their grazing time during the year on millet and rice residues in the rice production system in the interior delta of the Niger river (Dicko, 1983).

Alternative uses of crop residues in semi-arid areas may compete with their use as animal feed. Crop residues are crucial inputs to semi-arid cropping systems as they are recycled to return to the soil the nutrients extracted by crops. The restoration of soil fertility through crop residues permit continuous cropping of soils that receive limited or no chemical fertiliser. Crop residues form valuable sources of soil organic matter and minerals. In addition, they protect the soils against wind and water erosion and against high temperatures. Millet and sorghum stalks are also used as fuel and construction materials in semi-arid areas.

Genetic, agronomic and environmental factors as well as management practices influence the availability and the feeding value of cereal crop residues (Preston and Leng, 1984; Powell, 1985; Reed, Yilma and Fussel, 1988; Egan, 1989; Thorne and Carlaw, 1991; Reed, 1992; Van Soest, 1995). More precisely, the feeding value of cereal crop residues depends on crop species, varieties, tannin content, stage of harvest, length of storage, proportion of leaf to stem, fertiliser application and soil fertility, weathering and maturity (Preston and Leng, 1987). These factors determine the chemical composition of the plant material and the different associations of plant structural constituents that affect their degradability by micro-organisms in the rumen. A main characteristic of cereal crop residues is that they consist of highly lignified cell wall materials, which often constitute up to 80% of the dry matter (Theander and Aman, 1984). These plant materials have little soluble cell content and therefore have to be digested by microbial fermentation. The presence of lignin limits the ability of rumen micro-organisms to digest the cell wall polysaccharides of cereal roughages. Cereal crop residues are also known to have a low crude protein content, but this may vary over a large range and the major part of the protein is likely to be associated with the cell wall. Although the mineral content is low and generally unbalanced, it may be quite adequate for the maintenance and work by ruminants (Preston and Leng, 1987).

Powell (1985) and Reed *et al.* (1988) investigated factors that affect the nutritive value of sorghum and millet crop residues in the semi-arid areas and the sub-humid zones of Africa. The ratio of leaf to stem in the millet and sorghum stover is an indicator of the stover quality. It determines the level of intake and digestibility of these feeds by cattle. When cattle were allowed to graze millet and sorghum crop residues in the field, they consumed 61% and 81 % of sorghum and millet leaves, respectively and 40 % and 47 % of stems, respectively, during the 8 weeks they had access to these feeds (Powell, 1985). Both crops have, on average, a 1:5 leaf stalk ratio on a wet-weight basis and a 1:3 ratio on a dry-weight basis. The crude protein content is higher in leaf (4.5% DM for sorghum and 6.8% DM for millet) than in stalk (1.1% DM for sorghum and 1.8% DM for millet). However the presence of phenolic compounds in sorghum leaves is a major factor limiting the digestibility of leaves of the bird-resistant varieties of sorghum (Reed *et al.,* 1988). Table 8 illustrates the variations in fibre content, fibre digestibility and lignin content of 12 varieties of millet residues sampled at the ICRISAT Sahelian Centre in Niger.

Table 8.
Average content of neutral-detergent fibre (NDF), digestibility of NDF (DNDF) and content of lignin in leaf blades, leaf sheaths and stems from crop residues of 12 millet varieties (Reed *et al.*, 1988).

Plant component	NDF (% OM)	DNDF (%)	Lignin (% OM)
Leaf blade			
Mean	59.9	60.1	3.9
Range	57.7-63.0	55.7-62.2	3.5-4.5
Leaf sheath			
Mean	69.2	42.4	5.1
Range	65.5-70.8	38.1-44.9	4.8-5.9
Stem			
Mean	76.2	30.7	8.7
Range	72.5-79.6	27.6-35.2	7.6-9.7

Other important feed resources from locally grown crops for draught oxen in semi-arid areas are groundnut and cowpea hays, cotton seeds and groundnut and cotton cakes. Legume hays are rich in protein and are highly digestible. They are therefore appropriate feed supplements for draught oxen fed on fibrous roughages. Competition for the use these residues between draught oxen and other classes of cattle or other species of livestock on farm, may limit their availability for draught oxen. The availability of legume hays on-farm is also reduced because of an attractive price when they are marketed in cities. Cotton seeds and groundnut and cotton cakes are also used to supplement the ration of draught oxen. However the extensive use of these feed resources is limited by their high price. In some countries, government policies have been formulated to supply draught oxen owners with subsidised cotton seeds or cotton cake.

Feeding management systems for draught oxen

At the onset of the cropping season, draught oxen are drawn from the main herd and kept in the vicinity of the household. When they are not worked, draught oxen can be either tethered in stables and fed cut-and-carry forages or tethered in fallow areas. They can also graze freely on fallow pastures during the hours they are not working. Draught oxen are generally restrained in their movement to prevent damage to crops due to animal invasion. They can be disadvantaged compared to other classes of cattle because of this restriction in movement. Moreover these animals have reduced time available for feeding during working days while their nutrient requirements have increased due to work. When natural pastures are well established during the cropping season, they become abundant and they are of good quality. These animals can therefore compensate for the limited time available to eat by increasing their eating rate when they grazed natural pastures (Table 9). This was suggested by Dicko and Sangare (1984) who investigated the feeding behaviour of draught oxen grazing natural pastures in the semi-arid areas of Mali before and during the cropping season. They found that the number of bites per hour during hours they spent eating was higher on working than on non-working days (Table 9).

After the harvest of the main crops by October, draught cattle that are not being used for carting are returned to the main herd. Cereal crops (millet, sorghum, rice) residues remaining in crop fields become the main source of roughage during this period of the year. In certain areas millet and sorghum stover can be collected and stacked for use during the hot dry season. Richer feed resources such as groundnut and cowpea hays are also systematically collected and stored for later use.

Table 9.
Time spent grazing, eating and walking and eating rate of village draught oxen grazing natural pastures during working (WD) and non-working days (NWD) during different months in the semi-arid areas in Mali (Dicko and Sangare, 1984).

	May	June	July		August	
	NWD	NWD	NWD	WD	NWD	WD
Time spent at pastures (h/d)	11.7	10.5	9.3	5.2	7.0	5.0
Time spent eating (h/d)	5.3	6.3	5.4	4.0	4.9	3.8
Time spent walking (h/d)	2.9	2.7	2.2	0.8	0.5	0.3
Number of bites/day	4405	8973	10067	7825	10945	9466
Number of bites/ h[1]	831	1424	1864	1956	2234	2491

1: Calculated from the original data as the number of bites per day divided by the number of hours spent eating

Animals spent less time walking when they grazed crop residues in fields surrounding the compounds (Table 9). The hot dry season in semi-arid areas, from March to June-July, is the most critical feeding period of the year. Animals continue to rely on natural pastures and crop residues which become scarce because of their natural decay and losses through fire and grazing. Animals have to travel long distances in the search for increasingly scarce feed. This is conducive to high energy expenditures and maintenance costs when feed is in short supply.

Seasonal changes in live weight of draught oxen

There is marked seasonality in the pattern of LW change of draught oxen in semi-arid areas which reflects the variation of feed availability and quality during the year. Feed shortages during the dry season lead to dramatic LW losses. Wilson (1987) monitored the LW of working oxen in Mali for 5 years. The minimum LW at the start of the cropping season (241 kg) was found to be only 73 % of the maximum LW of 332 kg in November, at the beginning of the dry season. Reh (1981) found also that the LW of draught cattle at the onset of the rainy season was 17 % lower than LW during the early dry season in Senegal. Hence draught oxen are at their minimum LW at the onset of the rainy season when energy demand for cropping operations is at peak because they suffered from severe feed deficit during the dry season. These LW changes are seen as a major constraint to the adequate supply of draught animal power to the cropping sector in semi-arid areas where timeliness in field operations is crucial for successful farming. These LW losses are exacerbated by work during the cropping season. Dicko and Sangaré (1984) reported that, during the 3-week period of ploughing, draught oxen lost 26-28 % of the of their initial LW at the start of the ploughing period.

3.2.2. Intake and digestibility of feed by draught oxen

Control of feed intake in ruminants

Voluntary feed intake (VFI) is the quantity of feed eaten by an animal in a given time. VFI is one of the most important factors that determine animal productivity. The quantity of nutrients available for maintenance and productive purposes depends on the level of VFI. The regulation of feed intake in ruminants is a complex process that involves a range of factors including the animal's metabolism, gastrointestinal function, feed characteristics and the environment (Weston, 1985). Forbes (1986, 1995) reviewed theories of control of feed intake, the role of the central nervous system and physiological and dietary determinants of feed intake. Classical theories based on single factors such as gastric distension, blood glucose concentration, body temperature, or fat stores are unlikely to yield a comprehensive model of feed intake regulation in ruminants. It is more likely that the feeding centres of the hypothalamus integrate signals generated from different receptors to control feed intake in a additive way (Forbes, 1986). The inhibition of feed intake is the result of the stimulation of stretch receptors in the gut and/or chemoreceptors sensitive to acetate in the rumen and to propionate in the liver. The rate of removal of acetate has an important bearing on feed intake. Preston and Leng (1987) hypothesised that acetate clearance is a major integrating factor that ultimately allows the expression of feed intake.

Factors affecting feed intake

Physiological factors

Changes in the physiological state of ruminants influence feed intake. VFI increases as animals grow, but not in direct proportion to live weight (Forbes, 1986). Studies of best fit of intake data with body weight reveals powers from 0.5-0.8 (Colburn, Evans and Ramage, 1968).

Periods of reduced growth rate due to feed restriction or other stresses are followed by rapid growth when nutrition improves for restricted animals as compared to unrestricted animals. This is known as compensatory growth attributed to higher feed intake, increased gut content and improved efficiency of conversion due to lower maintenance requirements (McDonald, Edwards and Greenhalph, 1981).

The increased need for nutrients for foetal development causes increased intake in pregnant animals in mid-pregnancy. However, in late pregnancy feed intake is depressed by the reduced capacity of the rumen resulting from increased foetus size. (McDonald *et al.*, 1981). Lactation causes increases in feed intake. This is thought to be the result of a higher nutrient demand and the consequent rapid removal of metabolites stimulating chemoreceptors (Forbes, 1986).

Dietary factors

Dietary characteristics that affect feed intake are attributes of the physical properties, chemical composition and the availability of the feeds (Campling and Lean, 1983; Forbes, 1986). Dietary bulk and consequent distension of the rumen, digestibility, energy and protein concentrations, nutrient deficiencies or imbalance are dietary characteristics that influence VFI.

Evidence of the limiting effect of gastrointestinal fill on VFI is given through the feeding of low density diets and by displacement of gastrointestinal space by inert materials (Van Soest, 1983). The positive effect on intake of the reduction of the structural volume of feeds by grinding is an additional evidence of limitation of feed intake by rumen distension (Campling and Lean, 1983). Van Soest (1983) stresses the importance of plant cell wall constituents measured by acid detergent fibre as the primary restrictive determinant of intake. This is referred to as the physical control of feed intake in ruminants. The disappearance of feed from the rumen and therefore the reduction of rumen distension is determined by the rate of digestion and the rate of passage of feeds through the gastrointestinal tract. Rate of passage that refers to the flow of undigested residues through the digestive tract is a function of the rate of reduction in particle size of the units of structural carbohydrates. Particles must be reduced to a size (< 1 cm) and specific density (1.2 - 1.6) appropriate for propulsion through the reticulo-omasal orifice (Teleni and Hogan, 1989). Particle breakdown to smaller sizes results from rumination and cell wall communition in the rumen by microbial attack. Fibrous feeds with high cellulose content are digested relatively slowly and have a higher mean retention time in the gastrointestinal tract.

Beside the physical control of feed intake, a metabolic mechanism was also suggested to regulate VFI in ruminants after the observation of reduced feed intake when short chain fatty acids were infused into sheep (Forbes, 1995). Both physical and metabolic mechanisms can be involved in the regulation of VFI depending on the diet digestibility and energy concentration. As the feed digestibility improves due to its higher energy concentration, the metabolic regulation of feed intake becomes dominant. Apparent digestibility of 67% was found as the inflection point below which intake is positively associated with digestibility and above which intake is negatively associated with digestibility (Conrad *et al.*, 1964). This point of inflection is not however fixed and is dependent upon the density of the diet, the energy demand (Van Soest, 1983) and the rate of disappearance of feed from the rumen (Forbes, 1986).

Diet nutrient deficiencies or imbalances influence VFI. Ruminants require a supply of rumen degradable protein so that the ammonia concentration in the rumen fluid is sufficient for microbial growth. Protein deficiency in the diet therefore leads to reduced microbial activity and reduced diet digestibility (Preston and Leng, 1987; Forbes, 1995).

Environmental factors

The most important environmental variable that can interfere with VFI of ruminants in the semi-arid areas is the high ambient temperatures which impose heat stress on the animals. The physiological responses in heat stressed animals are strategies to maintain body temperatures. The reduction in feed intake detected in animals subjected to heat stress is meant to reduce heat produced through ruminal fermentation (Collier and Beed, 1985). Because of their higher thermogenic potential, the consumption of highly fibrous, poorly digested diets are more likely to be reduced in heat stressed animals than intake of the more digestible diets (Curtis, 1983). High body temperatures reduce rumen contractions and increased mean retention time (Christopherson and Kennedy, 1983; Collier and Beed, 1985). This may be mediated by hormonal mechanisms (Thomas and Pearson, 1990) as plasma concentration of thyroxine is markedly reduced in heat stressed animals (Johnson, 1987). This may be beneficial to the digestibility of feeds as digesta stays longer in the gut. However, the reduced passage rates and the increased water consumption due to heat stress may increase the gut fill which has negative effect on feed intake (Collier and Beed, 1985; Forbes, 1995).

3.2.3. Effect of work on intake and digestibility of feed

The potential effect of work on feed intake may be brought about by direct or indirect mechanisms. Direct effects of work on feed intake occur through physiological changes resulting from exercise. Muscular activity induces a higher metabolic rate in working animals 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 (Preston and Leng, 1987). Pearson and Lawrence (1992) reported instances of animals resting after work rather than eating when oxen returned from ploughing for 5 h/day. Animals may therefore prefer to rest after periods of work. They have therefore less time to comminute feed (Pearson and Smith, 1994). Physiological changes in working animals also include higher body temperature due to heat gained from solar radiation and increased metabolism during work. The resulting heat stress could depress feed intake in working animals (Collier and Beed, 1985).

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

Weston (1985) pointed out that work has the potential to affect digestibility directly and indirectly through changes in a range of factors including increases in body temperatures, feed particle residence time in the gastrointestinal tract, and effectiveness of mastication on particle breakdown. Positive effects of work on feed digestibility may stem from the enhancement of microbial fermentation through greater mixing of rumen contents due to exercise (Matthewman and Dijkman, 1993) and higher but moderate body temperatures resulting from work. Detrimental effects of work on feed digestibility may result from the shift of blood flow from the gut to muscles and peripheral tissues, reduction in meal frequencies (Matthewman and Dijkman, 1993), and the less thorough mastication of feed because of limited time to ruminate (Pearson and Smith, 1994).

A clear understanding of the relation between work and digestive physiology is a fundamental aspect of research on the nutrition of working ruminants. Apart from the work done by Brody (1945) in the 1940s until recently, little research endeavour has been directed to the nutrition of draught ruminants. With the absence of direct data from ruminants, information on the physiological changes associated with exercise in horses was extrapolated to working ruminants. For instance, Weston (1985) anticipated increased feed intake as a response to work in working bovine. He based his hypothesis on the stimulation of the feed intake seen in laboratory rats (Mayer *et al.* 1954) and in horses (Orton, Hume and Leng, 1985) due to the increased energy demand for work.

Table 10.
Effects of work on intake and digestibility (diges.) of feeds by cattle and buffaloes.

Animals	Diet	Response		Authors
		intake	diges.	
Cattle buffalo	Straw + concentrate	1: - 2: NE		Pearson and Smith, 1994
Buffalo (cows)	straw + urea + miner.	1: NE		Bakrie and Teleni, 1991
Buffalo cows	straw +hay	1: NE	NE	Bamualim and Ffoulkes, 1988
Cattle (cows)	hay	1: +	+	Zerbini *et al.*, 1995
Cattle (oxen)	Hay +concentrate	1: NE 2: 3: -	NE NE +	Pearson and Lawrence, 1992
Cattle (steers)	hay +urea +minerals	1: NE		Backrie *et al.* 1988
Buffalo (cows)	Straw +concentrate	1: -	NE	Pieterson and Teleni, 1991
Cattle+ buffalo	straw +urea +minerals	1: +		Bachrie *et al.*, 1989
Cattle cows	straw +concentrate	1: NE		Matthewman *et al.*, 1993
Cattle (oxen)	straw +tree fodder	1:-	NE	Pearson et al., 1990
Cattle (oxen)	straw +concentrate	1: NE		Pearson *et al.*, 1988
Buffalo cows	straw + hay	1: + 2: NE	+ NE	Ffoulkes, 1986
Cattle	straw + hay + urea	1: -	+	Soller *et al*, 1991

1,2,3: Experiment number; NE: no significant effect; +: significant increase; - : significant decrease

The realisation that adequate feeding was a major constraint to the supply of farm power using draught animals in many developing countries has led to the initiation of many studies on the nutrition of these animals during the last 15 years. The elucidation of the relation between work and the digestive physiology of draught ruminants has been a main subject of investigation since 1986. The results of 16 experiments in 13 studies investigating the effect of work on feed intake and digestibility by working cattle and buffaloes in Africa, South America, Asia and Australia were reported (see references in Table 10 inspired by Mathers and Otchere, 1993). Work caused a significant increase in feed intake in 3 cases, a significant decrease in 5 cases and no significant effect on feed intake in 8 cases out of the 16 experiments. Inconsistencies of these results were attributed to differences in experimental conditions i.e. conditions of the animals, intensity of work, levels of feeding and interval of measurements of digestive parameters (Ffoulkes and Bamualim, 1989). Contrasting results are also reported regarding the effect of work on the digestibility of feed by working ruminants (Table 9). Work did not have any significant effect on the digestibility of feed in 6 experiments and had a positive effect in 4 experiments out of 10 where digestibility results were reported (Table 9).

3.3. Experimental work: Intake, digestion and rate of passage of feed through the gastrointestinal tract in draught oxen fed crop residues and working under hot conditions

3.3.1. Material and methods

Experiment 2

Animals and feeding

This experiment was conducted from July to September 1993 at the ICRISAT Sahelian Centre in Niger. Eighteen oxen, aged 4-8 years, bought in the local livestock markets, were used in this experiment (Table 11). All animals were dewormed and vaccinated against Rinderpest, Anthrax, and Pasteurellosis. Oxen were housed in individual concrete floor pens roofed with zinc sheets. Each pen was fitted with a halved empty oil drum as a feed trough and a graduated metal water bucket to water the animals. Individual pens were separated with wooden planks to prevent mixing of feed spillages.

Table 11.
Age (year) , initial body weight (kg) and initial body condition score of oxen used in Experiment 2.

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

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/kg $LW^{0.75}$/day. 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. Feed troughs and buckets were withdrawn from all the pens when oxen on an exercise schedule were working. Therefore all animals had equal time of access to feed but 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 feed. Table 12 shows the chemical composition of the millet stover and concentrate. 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. Treatments were allocated as 3 × 3 latin squares (3 squares) with 3-week periods as columns and ox teams as rows. Treatments imposed were:

1) No work (work 0 hours/day)

2) work 2 hours daily

3)Work 4 hours daily.

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 group 1, 2 and 3 were allotted to square 1, 2 and 3, respectively so that each square was formed with animals of similar live weight. The experiment lasted 11 weeks, which were divided into three 3-week periods. Each team worked for 3 days/ week. Animals worked pulling a loaded sledge along a flat circuit or performing common field operations (cultivation). Teams working for 4 h/day worked 2 h in the morning and 2 h in the afternoon. The experimental protocol followed in each period was:

Week 1-2: Adaptation to the treatment (work pulling loaded sledges with the equipment harnessed to the animal) with measurement of feed and water intake.

Week 3-5, Period 1: Teams 1, 4 and 9 were at-rest, Teams 2, 6 and 8 worked for 2h/day, Teams 3, 5 and 7 worked for 4 h/day.

Week 6-8, Period 2: Teams 2, 6 and 8 were at-rest, Teams 3, 5 and 7 worked for 2 h/day, Teams 1, 4 and 9 worked for 4 h/day.

Week 9-11,Period 3: Teams 3,5 and 7 were at-rest, Teams 1, 4 and 9 worked for 2 h/day, Teams 2, 6 and 8 worked for 4 h/day.

During Periods 1, 2 and 3, the following measurements were carried out:

1) Work output, distance travelled and elapsed working time were continuously measured using the ergometer (Chapter 1).

2) Blood samples were taken every week for the determination of plasma urea-N and thyroid hormone concentrations.

3) Body weight was measured using a weighscale every week.

4) Feed offered and refusals were weighed every day. Refusals on the floor and feed left in troughs were collected separately because of contamination of spillage by urine and water.

5)Water intake was measured each day.

6)Rectal temperature (see section 5.2.1 for details of the measurement of rectal temperature)

Laboratory analysis

Daily feed samples were pooled each week, a sample taken and dried in a forced air-oven to constant weight at 55 °C and ground to pass a 1-mm screen before being analysed. 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).

Table 12.
Chemical composition of the millet stover and the concentrate fed during Experiments 2 and 3. Except for dry matter (DM) and energy (GE), values are expressed as percentage of DM.

Feed component	Millet stover		Concentrate	
	Expt 2	Expt 3	Expt 2	Exp 3
Dry matter(DM, %)	90.2	94.0	90.5	93.5
Crude protein (CP)	3.3	3.56	29.3	17.7
Gross energy (GE, MJ/kg DM)	17.5	17.97	18.1	14.7
Ash	3.6	3.7	10.2	24.4
Organic matter (OM)	96.4	97.3	89.8	75.6
Neutral detergent fibre (NDF)	78.9	78.1	29.3	19.7
Acid detergent fibre (ADF)	53.9	51.9	13.1	7.2
Hemicellulose	27.4	26.1	16.2	12.5

Plasma thyroxine (T_4) was analysed using the fluorescence polarisation immunoassay technique with an Abbot TDx Analyser (Abbot laboratories, USA). The analysis of plasma triiodothyronine (T_3) used the IMx total T_3 assay based on the

Microparticle Enzyme Immunoassay Technique (Abbot Laboratories, USA). Plasma urea-N (PUN) was assayed by an enzymatic method using a Bayer Diagnostic RA-2000 Random Access Chemistry Analyser (Bayer Diagnostics, Basingston, Hants, UK).

Data analysis

The following statistical models were used to analyse feed and water intakes, weight change, plasma thyroid hormones and urea-N concentrations.

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

where:

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

μ : overall mean

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

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

$P(S)_{(i)k}$: effect of the k^{th} experimental period nested in the 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

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

$W{*}T_{(i)jm}$: 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.

Team within square [(T(S)] was used as the error term to test the effect of treatment. The sums of square for treatment and week were further partitioned into single degrees of freedom using polynomial contrasts. Weekly live weight changes were estimated by regression analysis and were further subjected to analysis of variance using generalised linear models (SAS, 1985).

Experiment 3

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 (±37) kg, at the start of the experiment, were used. They were housed as in Experiment 2 (section 3.2.1).

Oxen were fed chopped millet stover *ad libitum* except during the working hours. Millet stover was supplemented with a concentrate mix made up of wheat bran (400 g/kg), groundnut cake (300 g/kg), rock phosphate (100 g/kg), crushed bone (100 g/kg) and common salt (100 g/kg). The concentrate was fed at a daily rate of 10 g DM/kgLW$^{0.75}$ at 12:00 hours after the morning working session. Daily feed allowance was adjusted so that refusals were at least equal to 50% of feed offered.

Experimental design

The treatments imposed were:

1) No work (Work 0 hours/day)
2) Work 2.5 hours daily
3) Work 5 hours daily

Work consisted of pulling a metal sledge loaded with weights so that the draught force exerted was equivalent to 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.

A latin square crossover design was used. Treatments were allocated as 3 × 3 latin squares with 2-week periods as columns and individual animals as rows. Twelve oxen were assigned to the three treatment groups, 2 teams in each group. The experiment lasted 12 weeks divided into five 2-week periods. Observations were repeated in both weeks in periods 1, 3 and 5. No treatment was applied during periods 2 and 4 to dissipate carry over effects from previous periods. The experimental protocol followed in each period was:

Period 1: Weeks 1 and 2:	Adaptation to treatment with measurement of food and water intake.
Period 2: Weeks 3 and 4:	Oxen no. 8, 12 (team 1), 11 and 16 (team 6) were at-rest, Oxen no.1, 3 (Team 2), 9 and 17(Team 5) worked for 2.5 h/day, Oxen 10, 14 (Team 3), 4 and 6 (Team4) worked for 5 h/day. Measurement of food and water intake. Measurement of work, distance travelled and elapsed working time. Measurement of rectal temperature Blood sampling Total faecal collection during week 4 Individual faecal samples collected during week 4 for measurement of Cr-fibre. Observation of feeding behaviour.
Period 3: Weeks 5 and 6:	All teams were at-rest, no measurement was carried out.
Period 4: Weeks 7 and 8:	Teams 3 and 4 were at-rest, Teams 1 and 6 worked for 2.5 h/day, Teams 2 and 5 worked for 5 h/day. Measurements were as in Period 2 except for the collection of individual faecal samples for Cr-fibre determination and the observation of the feeding behaviour which were not carried out during this period.
Period 4: Weeks 9 and 10:	All teams were at-rest, no measurement was carried out.

Period 5: Weeks 11 and 12: Teams 2 and 5 were at-rest, Teams 3 and 4 worked for 2.5 h/day, Teams 1 and 6 worked for 5 h/day. Measurements were as in period 2, except for the feeding behaviour which was not carried during this period.

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 line of force on work load was then derived and used to determine the load required for each team so that the draught force exerted was equivalent to 10% the team live weight. The length of the circuit was 1020 m. The time taken to travel around the circuit was measured with a stop watch.

Intake and digestibility of feed: 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. Weekly proportions of leaves in the stover were determined as the product between the weight of leaves and the sum of the weight of leaves and stems sampled over the week. Daily feed allowance were measured daily. Feed and refusals sampling procedures for subsequent laboratory analysis were done as in Experiment 2.

Three digestibility trials were conducted. Total faecal collection was carried out for 7-day periods using faecal bags harnessed to oxen throughout the collection period. For each individual, the faecal bag was regularly emptied and the faeces weighed and placed into a bucket, stored in a cool place. At the end of each

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

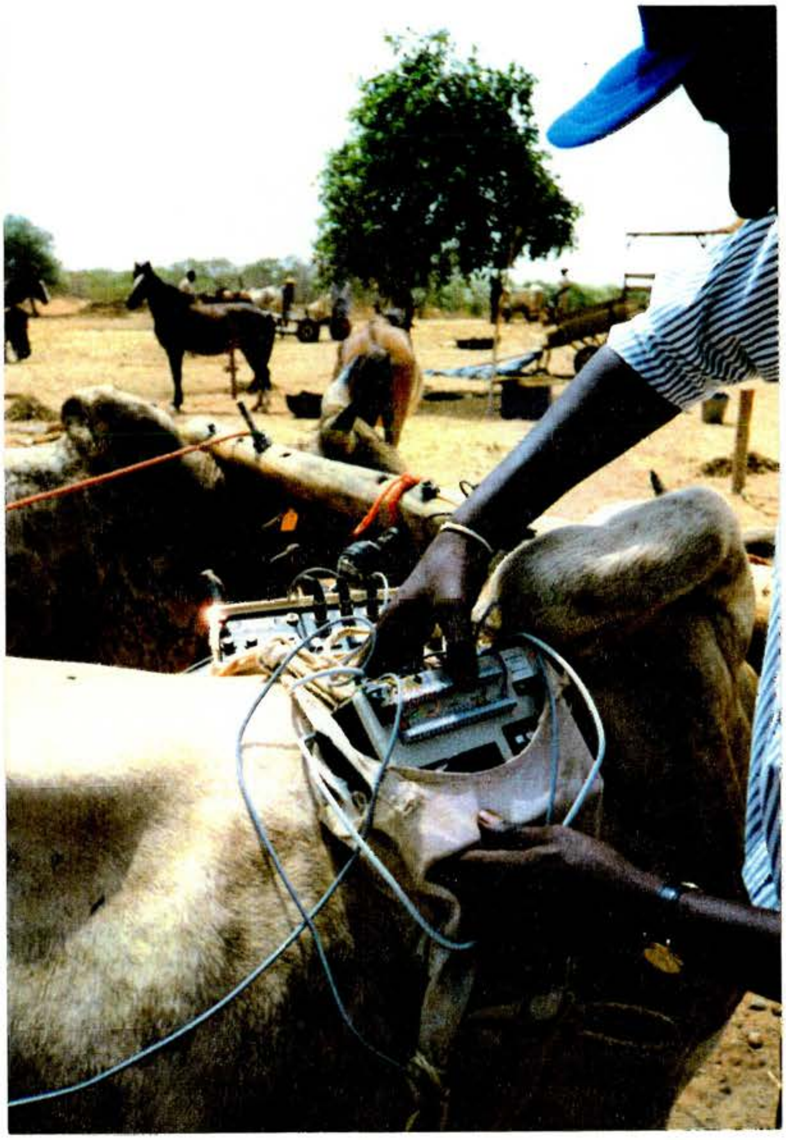


Plate 3. ***An ergometer Integration and Display unit (left pocket) and a datalogger (right pocket) contained in a backpack attached to an ox.***

day, faeces were mixed and a sample (5%) 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 feed: Sixty grams of chromium mordanted fibre, a solid marker, were fed on day 7 of the first and the second periods (Mathers, Baber and Archibald, 1989). On that day feed was withdrawn from pens at 14:00 until 23:00 when the markers were fed. At each sampling hour, previous faeces voided in the bag were mixed and a sample was taken. Faeces samples were collected at regular intervals as follows: day 8: 8:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00, 23:00 hours; day 9: 8:00, 12:00, 14:00, 16:00, 18:00, 22:00 hours; day 10: 8:00, 12:00, 16:00, 22:00 hours: day 11: 8:00, 12:00, 16:00, 22:00 hours; day 12: 8:00, 12:00, 16:00, 22:00 hours; day 13: 8:00, 16:00 hours; day 14: 8:00, 16:00 hours; day 15: 8:00, 16:00 hours. Individual faecal samples previously voided in the bag were thoroughly mixed and a sample was taken for the determination of DM and markers concentrations. Gastro-intestinal mean retention time was estimated using Grovum and Williams (1973) mathematical procedures, after a single dose of marker was fed.

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 scan observation technique was used: 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. Blood samples were collected as described in Experiment 2 (Section 3.3.1).

Laboratory analysis

Determinations on the feed, refusals and faeces samples are described in Section 3.3.1. Plasma T_3, T_4 and PUN were analysed as described in Experiment 2 (Section 3.3.1).

Statistical analysis

Data were analysed using SAS GLM procedures (SAS, 1985). The statistical model used to analyse daily dry matter intake (DMI), digestibility coefficients, and weight change included squares, oxen within squares, periods within squares and treatment. Orthogonal linear and quadratic polynomials were used to test the effect of treatment. 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

3.3.2. Results

Experiment 2

Climate and physiological responses to work

Minimum, maximum and mean ambient temperatures were 23.0, 35.0 and 29.3 ^{o}C when animals worked in the morning and 24.0, 36.0 and 31.7 ^{o}C when work took place in the afternoon. Minimum and maximum 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 12). Plasma T_4 concentrations were 56.3 (±1.2), 52.7 (±1.2) and 52.3 (±1.2) nmol/l for oxen working 0, 2 and 4h/d. Plasma T_3 concentrations were 0.95 (±0.03), 0.94 (±0.03) and 0.98 (±0.03) nmol/l for oxen working 0, 2 and 4 h/day. There was however 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 of 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 was significantly higher during week 2 than during weeks 1 and 3.

Table 13.
Least square means of plasma concentrations of thyroxine (T_4), triiodothyronine (T_3) and urea-N (PUN) for 18 oxen working 0, 2 or 4 h/day and blood sampled every week during 9 weeks (Experiment 2).

	n	**T_4 nmol**	**T_3 nmol/l.**	**PUN mmol/l**
Work level				
0h/d	27	56.3	0.95	4.00
2h/d	27	52.7	0.94	4.53
4h/d	27	52.3	0.98	4.83
s.e.	1.2	1.2	0.03	0.14
signif.:	NS	NS	NS	Linear**
Week				
1	27	57.9	1.05	4.33
2	27	52.64	0.84	4.77
3	27	50.79	0.98	4.27
s.e.	1.15	1.15	0.03	0.14
signif.:	linear*	linear*	linear* Quad**	Quad**

* : $P<0.05$, ** :$P<0.01$

Work performance

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 LW, 583 (CV=11%) W and 90 (CV=28%) W/100kg LW, 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 LW, 616 (CV=10%) W and 92 (CV=19%) W/100kg LW, respectively (Table 14).

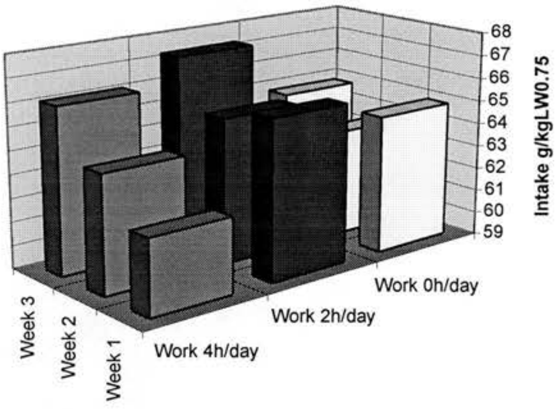
Feed intake

Daily dry matter intake (DMI) of millet stover was not significantly 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 $LW^{0.75}$ ($P<0.01$) and in g DM/kg LW ($P<0.05$). Daily feed intakes of oxen at-rest were 15.52 (±0.18), 15.48 (±0.18) and 15.89 (±0.18) g DM/day/kg LW in week 1, 2 and 3, respectively. The interaction between treatment and week was significant for DMI-g/kg LW and close to significance ($P=0.07$) for DMI-g/kg$LW^{0.75}$. Table 14 shows daily work characteristics, feed and water intake and weekly live weight changes. Feed intakes of animals working 2 and 4h/day include feed consumption of 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).

Water intake

There was no significant difference, due to work, in water consumption expressed in l/day, l/kg LW, l/kg $LW^{0.75}$ or l/kg DMI (Table 13). Oxen working 0, 2 and 4 h/day consumed 30.5 (±0.5), 30.2 (±0.5) and 30.3 (±0.5) l/day, respectively. Volume of water consumed per kg of DM eaten were 6.45 (±0.097), 6.32 (±0.097) and 6.58 (±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.

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)



Live weight change

Body weight change was significantly affected by work ($P<0.05$). Weekly weight gains were 3.72 (±0.76), 1.58 (±0.84) and -2.19 (±0.82) kg for oxen working 0, 2, 4 h/day, respectively. The observed pattern of live weight change either weight gain or loss agrees well with the calculated pattern of live weight change. This is particularly true for oxen at-rest (Table 15). However the calculated energy balance overestimated weight losses for oxen working 4 h/day and underestimated weight gains for oxen 2 h/day.

Experiment 3

Physiological responses to work

There was a significant linear ($P<0.05$) increase in PUN concentrations as work level increased. PUN was 3.51 (±0.18), 3.81(±0.18) and 4.66 (±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 (±0.021), 0.043 (±0.021) and 0.094 (±0.021) mmol/l per week for animals working 0, 2.5 and 5 h/day, respectively.

Table 14.

Mean (CV%) daily work output, load, and power and mean (± s.e.) intake of millet stover, water intake and live weight change by 18 oxen during 9 weeks when they worked for 0, 2 or 4 h per day, 3 days per week during 3-week periods (Experiment 2).

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 LW)	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				
n	54	48	48	
kg DM	4.72 ± 0.045	4.78 ± 0.049	4.60 ± 0.049	NS
g DM/kg LW	15.46 ± 0.17	15.94 ± 0.19	15.50 ± 0.19	NS
g DM/ kg $LW^{0.75}$	64.40 ± 0.65	66.06 ± 0.72	64.04 ± 0.72	NS
Daily water intake				
n	54	48	48	
litre (l)	30.5 ± 0.47	30.2 ± 0.51	30.3 ± 0.51	NS
l/kg LW	0.099 ± 0.001	0.099 ± 0.002	0.101 ± 0.002	NS
l/kg $LW^{0.75}$	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				
n	18	16	17	
kg/week	3.72 ± 0.76	1.58 ± 0.84	-2.19 ± 0.82	

The number of observations were 54, 48 and 48 for oxen working for 0, 2 and 4 h/day, respectively

Plasma T_4 concentration was significantly 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 17). This decrease was highest as work load increased. The rate of change of T_4 was -0.16 (±0.18), -0.54 (±0.18) and -1.02 (±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 (±0.23), 0.61 (±0.23) and 0.55 (±0.23) nmol/l for animals working 0, 2.5 and 5 h/day, respectively.

Table 15.
Metabolisable energy intake, energy used for work, energy used for maintenance and energy balance of oxen working 0, 2 or 4 h/day during 3 days per week for 9 weeks (Experiment 2)

	Work 0 h/day	Work 2 h/day	Work 4 h/day
Live weight (kg)	305	300	297
Daily energy intake[1], MJ ME	50.9	51.3	49.7
Daily energy used for work[2], MJ NE	0	7.2	15.2
Dailynergy used for maintenance[3], MJ NE	28.1	28.9	28.8
Daily energy balance MJ, NE	8.04	0.32	-8.7
Live weight change, kg/week[4]			
calculated from the energy balance	3.75	0.15	-4.06
observed	3.72	1.58	-2.19

ME: Metabolisable Energy, NE: Net Energy, MJ: Megajoules

1: 8.05 MJ ME/kg DM

2: Energy cost of walking = 1 j/m/kg as found in chapter 2, Efficiency of doing work = 0.32

3; Energy used for maintenance = $(\mathbf{a}\times\mathbf{b}\times(\mathbf{0.53}\times(\mathbf{LW/1.08})^{0.67}))\times\mathbf{c}$ (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 work done by the oxen during the experiment and which was not recorded, for instance walking to the site of where work takes place pulling loads.

4: 1 kg weight change ≡ 15 MJ NE (Lawrence and Becker, 1994).

Feed intake

Intake of millet stover was not significantly influenced by work. Table 16 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 LW, respectively. The relationship between intake and the proportion of leaf in the stover (LSR) is described by the following regression equations that show an improvement in feed intake as the proportion of leaves increased:

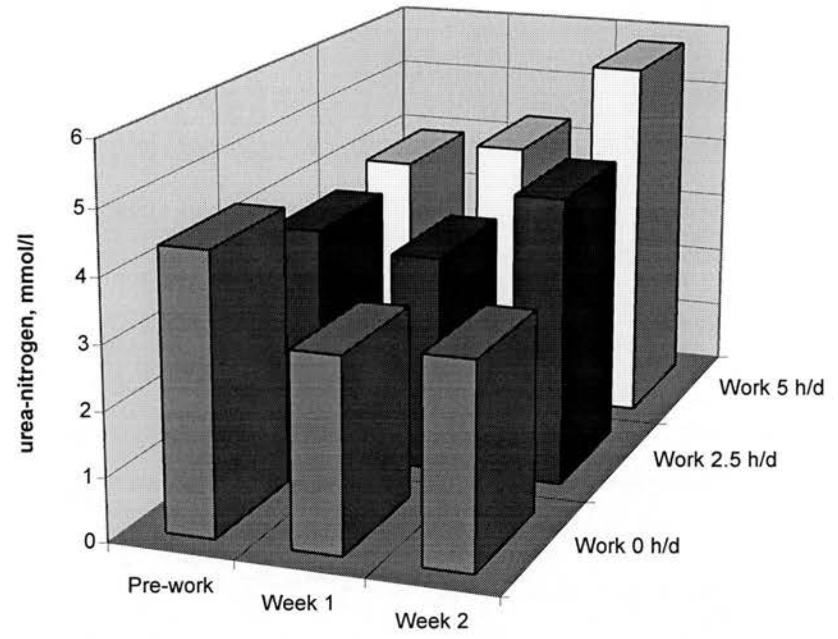


Figure 2. Plasma urea-N concentration of oxen before work and during 2 weeks when they worked for 0, 2.5 and 5 h/day (Experiment 3).

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

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

Water intake

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

Live weight change

Work caused LW 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.

Table 16.
Least square means of intake of millet stover, water intake, live weight and plasma concentration of urea-N (PUN) of 12 oxen working 7 days a week for 0, 2.5 and 5 hours/day (Experiment 3).

Work level	Work 0h/day	Work 2.5h/day	Work 5h/day	s.e.
Intake of millet stover				
n	24	24	24	
g/kgLW	15.13	16.22	16.15	0.20 NS
g/kgLW$^{0.75}$	61.36	65.82	65.51	0.83 NS
Water intake				
n	168	168	168	
l/day	21.35_a	25.200_b	28.510_c	0.380
l/kgLW	0.079_a	0.093_b	0.108_c	0.014
l/kgLW$^{0.75}$	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]				
n	36	36	36	
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]				
n	24	24	24	
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;
a: Values in the same row with different subscript are significantly different:

Coefficients of digestibility of feed

There was no significant effect of work on the digestibility of DM, OM, ADF, NDF, hemicellulose (HEM) and GE. Table 17 shows coefficients of digestibility for different work loads. Increases in the proportion of leaves in the feed offered improved digestibility coefficients as illustrated by the regression of digestibility coefficients on the proportion of leaf in the stover (LSR) given in the following equations:

$$DM = 0.03(\pm 0.08) + 0.69(\pm 0.08) \times LSR \qquad P<0.01, R^2 = 0.68$$

$$\mathrm{ADF} = 0.25(\pm 0.04) + 0.52(\pm 0.08) \times \mathrm{LSR} \qquad P<0.01,\ R^2 = 0.52$$

$$\mathrm{NDF} = 0.187(\pm 0.04) + 0.68(\pm 0.08) \times \mathrm{LSR} \qquad P<0.01,\ R^2 = 0.69$$

$$\mathrm{OM} = 0.06(\pm 0.05) + 0.70(\pm 0.09) \times \mathrm{LSR} \qquad P<0.01,\ R^2 = 0.65$$

$$\mathrm{HEM} = 0.14(\pm 0.05) + 0.87(\pm 0.09) \times \mathrm{LSR} \qquad P<0.01,\ R^2 = 0.72$$

$$\mathrm{GE} = 0.12(\pm 0.04) + 0.67(\pm 0.08) \times \mathrm{LSR} \qquad P<0.01,\ R^2 = 0.66$$

Rate of passage of feed

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 17 for Cr-fibre, a solid-particle marker. 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. The quadratic effect of work on MRT was significant ($P<0.05$). The MRT for animals working 2.5 h/day (78.2±2.3 h) was lower than MRT for animals working 5 h/day (82.2±2.3 h) or for animals at-rest (88.9±2.3 h).

Feeding behaviour

Work did not significantly affect time spent eating and ruminating (Table 17). There was also no significant difference, due to work, in eating and rumination rates.

3.3.3 Discussion

Heat stress

Since animals respond to heat stress by reducing their thyroid activity (Johnson, 1987, Youssef, 1987), significant differences in plasma levels of thyroid hormones between working and non-working animals were expected. This is because heat stress may be more pronounced in working animal as compared with animal at-rest due to theextra body heat gains from increased muscle metabolism in the working animal.

Table 17.
Effect of work on food digestibility, gastrointestinal rate of passage of solid particles, thyroxine (T_4) and triiodothyronine (T_3) plasma concentrations, and feeding behaviour parameters in 12 oxen which worked 0, 2.5 or 5 h/day pulling 10% of their live weight (Experiment 3).

Work level	Work 0h/day	Work 2.5h/day	Work 5h/day	s.e.	Significance
Digestibility (%)					
n	12	12	12		
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]					
n	36	36	36		
Before work	48.6	45.3	48.0	2.6	Week***
Week 1	49.0	44.4	38.7	2.6	Week×Work*
Week 2	45.5	34.6	27.7	2.6	
T_3 (nmo/l)[1]					Week:linear*
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
$1/k_1$ (h)	56.9	49.1	52.3	2.8	NS
$1/k_2$ (h)	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;
* : $P<0.05$, h; hour, NS: not significant, DMI: dry matter intake.

However during Experiment 2 of the present study, plasma thyroid hormone concentrations were similar for all oxen either working or at-rest. The absence of significant difference in plasma T_3 and T_4 concentrations between working oxen and oxen at-rest may be accounted for by the fact that oxen at-rest were sufficiently heat stressed by radiant heat gains. They were exposed to solar radiation and ambient temperatures were high. Another explanation is that the work load did not cause a level of heat stress that could induce significant changes in plasma thyroid hormone concentrations in the working animals.

During Experiment 3, plasma concentrations of T_3 and T_4 were decreasing 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). Heat stress reduces thyroid activity leading to decreased plasma concentration of T_3 (Johnson,1987; El-Nouty and Hassan, 1983). During experiment 3 oxen at-rest were not exposed to solar radiation and ambient temperatures were lower than during Experiment 2. 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. The higher heat load of working oxen, as compared with oxen at-rest, probably led working oxen to consume significantly more water than non-working oxen during Experiment 3.

The reduction of T_3 plasma concentrations during the 2-week experimental periods paralleled the reduction in LW of oxen observed during Experiment 3. Baccari, Johnson and Hahn (1983) and Johnson (1982) found similar patterns of parallel changes in T_3 concentration and growth in heifers exposed to thermal stress.

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

PUN

In both Experiments 2 and 3, there was a linear increase in PUN as the work level increased. This suggests that oxen were catabolizing amino acids to supply energy-yielding substrates to muscles during work. This is supported by the fact that oxen lost LW during working periods.

Water intake

There is little information on the extra water requirement for work. It is however often assumed that oxen need to consume more water during working days as compared with non-working days, particularly under hot conditions. Losses of water through evaporative cooling processes (sweating and panting) should be compensated by increased water intake.

During Experiment 2, both working and non-working oxen consumed similar amounts of water. Water consumption during successive 3-week periods when oxen were either working 0, 2 or 4 h/day were compared. Water consumption during working periods included water intake during days animals were not working. This is likely to mask any short term effect work would have on water consumption. Another explanation of the absence of difference in water intake between oxen in the different treatment groups during Experiment 2 is that the extent of heat stress in animals at-rest and in working animals were similar. This argument is supported by the fact that plasma thyroid hormone concentrations were at the same level in working and non-working animals.

During Experiment 3, water intake was significantly affected by work. As discussed above, the difference in heat stress between working and non-working animals during Experiment 3, as reflected by the significant differences in plasma thyroid hormone concentrations, was large enough to cause significant differences in water intake.

Feed intake

During Experiment 2, DMI of millet stover increased as the experiment progressed. A similar pattern of intake in working oxen was observed by Pearson and Lawrence (1992). They reported increased feed intake over time and suggested that animals were adapting to the feed during the experiment. The interaction between experimental 'weeks' and work was significant. DMI was depressed during the first week for oxen working 4 h/day. These animals were however able to increase DMI the following weeks. They were eating as much as oxen at rest or working 2 h/day by the third week. This suggests that when oxen are subjected to a high work load (more than 4 h/day), food intake is depressed during the first days of work and improves progressively the following days as oxen adapt to work. However this increase of food intake over time for oxen working 4h/day did not allow them to eat more than oxen at-rest or oxen working lightly. The overall food intake during the 3-week experimental periods were similar for all work treatments. Similarly, during Experiment 3, work did not have a significant effect on intake of millet stover.

Studies that investigated the effect of work on feed intake in cattle yielded contrasting patterns of relationships between these parameters. Significant depression of feed intake as a result of work is reported by Pearson (1990) and Pieterson and Teleni (1991). In contrast, Bakrie *et al.* (1989) and Zerbini *et al.* (1995) found significant increases in feed intake in response to work. Most results indicate however non-significant differences in intake in working animals as compared with animals at-rest (Barton and Saadullah, 1987; Bamualim, Ffoulkes and Fletcher, 1987; Bakrie, Murray and Hogan, 1988; Bakrie and Teleni, 1991; Soller, Reed, and Butterworth, 1991; Pearson and Lawrence, 1992; Matthewman, Oldham and Horgan, 1993, Van Thu, 1994). The absence of an effect of work on feed intake when time of access to feed was standardised, as in this study, was reported by Pearson and Smith (1994) in cattle, Bamualim and Ffoulkes (1988) in buffalo, Backrie *et al.* (1988), Bamualim *et al.* (1987) in Swamp buffalo cows and Pearson and Lawrence (1992) in cattle.

The effect of work on feed intake may result from the work stress and/or from the feed restriction during hours animals work (Pearson and Smith, 1994). These authors measured feed intake of animals in 3 treatment groups: 1: work for 5 h/day with 17 hours access to feed, 2: no work with 17 hours access to feed and 3: no work with 23 hours access to feed. Feed intake was reduced when access to feed was restricted for 7 hours/day and was further reduced when animals worked for 5 hours during these 7 hours of feed restriction. During both Experiments 2 and 3 of the present study oxen at-rest and working oxen had equal time available to eat. Feed restriction lasted for 2 or 4 hours during Experiment 2 and for 2.5 or 5 hours during Experiment 3. 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 feed intake in working oxen in these experiments. In fact, the monitoring of the feeding behaviour of animals showed that the time spent eating and ruminating was similar for animals working 0, 2.5 or 5 h/day. The absence of effect of work on feed intake may be associated with the fact that the period of feed restriction was not long enough for oxen to exhibit any short term response to work regarding their feed intake and their feeding behaviour. Pearson and Smith (1994) found also no effect of feed restriction with work on feed intake when feed restriction lasted only 4 hours.

During Experiment 3 when the quality of the millet stover was assessed, feed intake was significantly affected by the proportion of leaves in the stover and therefore by the quality of the diet. Powell (1985) showed the higher consumption of leaves of millet stover by cattle grazing crop residues and this was attributed to cattle being more selective of fine plant parts which had a higher protein content than stems and were more digestible. Thorne and Carlaw (1992) studied the stover quality in pearl millet according to environmental factors and plant characteristics. They found that environmental factors were more important in their effect on stover feeding value. They attributed the difference in feeding value due to the environment to the change in the relative proportions of the individual fractions-i.e. in the higher proportion of the more readily soluble leaf and sheath fractions. Reed *et al.* (1988) showed differences in the feeding value of sorghum and millet stover due to crop variety. Pearson and Lawrence (1992) studied the nature of the diet on the response to work. They concluded that time available to eat and ruminate was a constraint on feed intake when oxen were fed on a poorly digestible, fibrous diet as compared with more digestible diets.

Plant characteristics are an important determinant of feed intake in ruminants. Passage of food in the digestive tract and digestion are dependent on the reduction of particle size by chewing and microbial attack. Work and feed restriction can lead to reduced time to ruminate and to less thorough chewing of the food (Pearson and Smith (1994). Therefore intake and digestibility of foods with high cell wall content can be negatively affected because working oxen have limited time for the thorough chewing of food. The concept of additivity of hunger and satiety signals described by Forbes (1995) could give further explanation to the absence of difference or decrease in intake in working animals as compared to animals at-rest. It is likely that the physical limitation of feed intake imposed by the high fibre nature of the diet was more important than the metabolic stimulation of appetite caused by the increased energy demand for work. 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 feed intake in lactating cows. They further suggest that the long term regulation of feed intake takes a great significance in animal production and that this was driven by the energy requirements and the body reserves of the animal. The increase of feed intake over time seen in this study support the importance of the long term regulation of feed intake. Increased in feed intake was also reported by Zerbini *et al.*(1995) in draught cows working for a long period of time (90 days). The long term increased energy requirements for lactation and work may have caused increases in feed intake in these cows. 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 feed intake by draught oxen fed on roughages.

Digestibility and rate of passage of feeds through the digestive tract

In this study, DM apparent digestibility and the digestibility coefficients of food fractions were not significantly affected by work. These results agree with those reported by Pearson and Lawrence (1992) in Costa Rica, and Pearson (1990), Bamualim and Foulkes (1988), Ffoulkes (1986) and Pieterson and Teleni (1991) who found no significant differences in digestibility of food between working and non-working animals. In contrast significant increases in digestibility, as a result of work, were reported by Soller *et al* (1991) in Ethiopia, 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. Differences in diet quality were reported to be an important factor influencing the digestibility of food in working oxen (Pearson and Lawrence, 1992).

Rate-constants k_1 and k_2 representing the rate of passage of digesta through the rumen and in the lower tract, respectively, were not affected by work. This agrees with results reported by Zerbini *et al*.(1995) who found did not find significant differences in passage rate of Cr-mordanted hay between working and non-working cows. However, MRT of solid particles through the digestive tract was significantly lower for oxen working 2.5 h/day than 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.

Live weight change

During Experiment 2, oxen at-rest were able to gain LW whereas oxen working 2 h/day maintained their LW. During Experiment 3, oxen at rest maintained their LW while oxen working 2.5 or 5 h/day lost LW. This suggests that the energy intake from millet stover and concentrate (21.3 g/kg $LW^{0.75}$ during Experiment 2) was sufficient to allow weight gains in oxen at-rest. During Experiment 3, the level of concentrate offered was lower (10 g/kg $LW^{0.75}$) but animal had opportunities to select more leaves from the millet stover given as excess (50%) millet stover was offered .

During Experiment 2, work was not intense enough for oxen working 2 h/day and the energy intake assured the maintenance of LW for these animals.

The LW losses seen in oxen working 4 h/day during Experiment 2 and in animals working 2.5 or 5 h/day during Experiment 3 indicate that they could not meet their energy requirements for maintenance and work and therefore used their body reserves to perform work.

The calculated live weight change agreed well for the observed live weight change for oxen at-rest. However calculated and observed live weight changes were different although their patterns were similar. These estimates may be sensitive to the value of 15 MJ NE/ kg live weight gain (Lawrence and Becker, 1994). These discrepencies may also be related to the the precise recording of the activities of the oxen during the experiment. For instance the work done from the stables where the animals are harnessed to the site of work were not recorded. As pointed by Lawrence and Becker (1994), one priority for future research projects should be to ensure that wherever possible, the experimental design is modified to ensure the appripriate data (the distance travelled by animals to from the field, for instance) are collected.

Conclusions

A general picture which emerges from the results of this study is that oxen fed on crop residues or on roughages in general, can neither increase their feed intake nor use more efficiently the food eaten to compensate for the extra energy used for work. Therefore they mobilise their body reserves to supply muscles with energy-yielding nutrients. Hence weight loss 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. It was also observed that oxen could maintain their LW during resting periods when they were fed sufficient millet stover so that they could select leaves which were more nutritious. It is also noticed that the heat stress oxen were subjected to did not interfere with their digestive physiology. These results have many implications for the formulation of feeding strategies for draught oxen in semi-arid areas. First, since work and heat stress did not influence intake and digestibility of feeds, it may be relevant to predict feed intake of these animals using models developed for other classes of cattle. Second, ways to increase intake of roughages in semi-arid areas must be sought. Treatments of crop residues and the supplementation of these roughages with highly digestible forages supplying rumen degradable and rumen undegradable nutrients must be contemplated in semi-arid areas. Finally, since oxen cannot increase their nutrient intake during work when fed crop residues and that they use their body reserves to perform work, it is worthwhile investigating how the state of body reserves before work would affect work output. This is the topic of the next chapter.

CHAPTER IV

EFFECT OF BODY CONDITION PRIOR TO WORK AND WEIGHT LOSSES DURING WORK ON WORK OUTPUT

4.1. Introduction

Although the cropping season is relatively short in the semi-arid zones, many oxen are hired out or loaned to other farmers. Hence those oxen that are available may be used over extended periods for crop production and transport. While body condition and weight losses during work may not constrain performance when animals are only used for short periods (2 weeks), they take on greater significance where animals are used for longer periods (4+ weeks). Feed supplementation is expensive. Therefore, the level of weight loss that animals can tolerate before work output is affected needs to be determined. If the minimum working weight for cultivation can be estimated, then feeding strategies can be better planned in a farming system.

In this chapter the extent to which the state of body reserves before work and weight losses during work affect work performance of draught oxen are investigated. First, the utilisation of nutrients in working ruminants and the effect of diet restriction before work on work output are reviewed. Secondly, this chapter reports on an experiment that investigated the relationship between body weight, body condition, weight loss during work and work output of draught oxen. It was hypothesised that there is a minimum live weight:force below which work capacity of oxen is impaired and that the weight loss that can be tolerated depends on body condition at the start of work.

4.2. Literature review

4.2.1. Nutrient utilisation in working ruminants

Draught animals convert the chemical energy in the feed into mechanical energy used in agriculture and transport. This conversion of chemical to mechanical energy takes place in the muscle. Work is the result of muscle contraction driven by adenosine triphosphate (ATP) which serves as the principal immediate donor of free energy in biological systems. The power of muscle contraction depends on the availability of ATP and its rate of regeneration. ATP is resynthesised through the processes of aerobic or anaerobic phosphorylation depending on the rate of work. At submaximal rate of work, blood oxygen is not in short supply and energy is provided by aerobic metabolism of substrates using oxygen provided by the blood circulation. The reduction of substrates from fat and carbohydrates and their subsequent oxidation in the tricarboxylic acid cycle allows the continuous formation of ATP. At high rates of work, demand outstrips the supply of oxygen and the aerobic energy pathways can no longer entirely meet demand for energy. In this situation, energy is supplied through the anaerobic regeneration of ATP from creatine phosphate, ADP and the conversion of pyruvate to lactate during anaerobic glycolysis (eg. Pearson, 1985). This leads quickly to fatigue as lactate accumulates. However, draught animals usually work at a slow, steady pace so they rarely get into O_2 debt. Hence they rely almost entirely on aerobic oxidation to produce ATP (Lawrence and Becker, 1994).

In ruminant draught animals, the end-products of digestion are modified by the gut epithelium and the liver such that circulating substrates available for muscle metabolism are acetate, ketone bodies, long chain fatty acids (LCFA) and glucose. Additional energy sources that can be mobilised include the fat of adipose tissues and glycogen and fat present in muscles (Preston and Leng, 1987). The uptake of acetate by muscle is diet dependant. Low feed intake by the animal would result in a low uptake of acetate by muscle. Conversely, if the intake of feed was high, the uptake of acetate by muscle would be expected to increase (Teleni and Hogan, 1989). The role played by amino acids in the energetics of working ruminants is not yet clear. However, Teleni and Hogan (1989) suggest that amino acids can be used as direct energy sources or as glucose precursors. It is likely that amino acids are used as energy-yielding substrates if the ratio of energy-yielding substrates to amino acids were reduced or if the amino acids are not in a proportion conducive to protein synthesis (Teleni and Hogan, 1989).

Glucose and LCFA form the main metabolic fuels for muscle contraction in working ruminants (Pethick, 1984; Pethick, 1993; Harman and Pethick, 1994). These authors studied the whole animal and regional tissue metabolism of mature Merino sheep at rest or while walking at 1.25 m/s on 0^o incline (estimated as 30% VO_{2max}) for 4 h or 9^o incline for 2 h (estimated as 60% VO_{2max}). As the level of exercise increases, there is a parallel increase in LCFA blood concentration and of LCFA entry rates (Table 18). Clearly the LCFA play a central role as a main source of energy substrates for muscle contraction during prolonged exercise. Also during exercise there is a dramatic increase in glucose oxidation. This confirms that glucose is an important aerobic energy source for working ruminants. Ruminants appear to have the ability to maintain blood glucose concentration through an increase in the supply of glucose via gluconeogenesis and glycogenolysis. Harman and Pethick (1994) suggested also that ruminants may have the potential for greater rates of glycogen synthesis than previously thought. Propionate and amino acids may provide the working ruminants fed on roughages with glucose necessary for 6 h work during the day with temporary deficits made up from reserves of glycogen that must be replenished after work (Lawrence and Becker, 1994). Adult working oxen may not suffer much from glucose deficit, however multipurpose animals such as the lactating draught female ruminants or the growing draught ruminant fed on roughages may experience a competition for the use of glucose or glucose precursors necessary for different functions, i.e. lactation, reproduction, work or growth.

Because of the prominent role of LCFA as suppliers of energy-yielding substrates for muscle contraction, the low state of body reserves of draught animals at the start of the cultivation season was seen as a major constraint to the supply of draught animal power for crop production in semi-arid areas. This has led to the advocation of dry season supplementation of these animals so that they are in good condition when they resume work (Bamualim and Ffoulkes, 1989). Also, a number of studies have recently been conducted to investigate the effect of dry season supplementation of draught oxen on work performance.

Table 18.
Glucose and non-esterified fatty acid (LCFA) metabolism during exercise in sheep (Pethick, 1993).

Level of exercise	Rest	30% VO_{2max}	60% VO_{2max}
Glucose concentration (mM)	3.0±0.1	2.8±0.2	3.3±0.3
Hepatic release of glucose (mmol/h)	17±2	35±5	73±13
Glucose muscle uptake (mmol/h/kg)	1.1±0.2	2.4±1.0	4.8±0.8
Concentration of blood LCFA (mM)	0.1±0.01	0.8±0.1	1.2±0.2
Entry rate LCFA (mmol/h/kg)	0.1±0.02	1.7±0.1	3.0±0.1
Contribution of LCFA to energy[1] expenditure (%)	14	117	122

1: Contribution to whole body CO_2 entry rate assuming a complete oxidation. However much of the LCFA are not oxidized in the short term since only around 30% can be recovered during the exercise period, indicating substantial re-estherification of fatty acids (Pethick, 1993)

4.2.2. Feed restriction and work performance

Draught oxen lose LW during the dry season and have minimal weight at the start of the cropping season (Section 3.2.1). This has an adverse effect on the performance of draught animals since power supply from these animals is a function of their body weight. The dry season LW losses parallel a depreciation of the body condition of draught oxen. These animals therefore have minimal body reserves which can be drawn upon during critical cultivation periods when farm energy demand is highest. These are also the periods when available feed resources do not match the nutrient requirements of draught oxen for maintenance, let alone work. The correction of the dry season feed deficit by providing draught oxen with supplementary food was recommended as a means to produce oxen in good condition and LW when work resumes. This would enable them to perform the required work right at the beginning of the cropping season. However, most of the studies that investigated the effect of dry season supplementation on draught oxen failed to show any significant beneficial effect of committing scarce feed resources on work output and consequently on crop production. In Ethiopia, Astatke, Reed and Butterworth (1986) investigated the effect of diet restriction on work performance and weight loss of local and crossbred oxen. The control group of oxen was fed 100% of their estimated ME energy requirements for maintenance and work for 5 h/day. The treatment groups of oxen was fed 75% of the control ration over the first 5 weeks and 50% thereafter. All animals lost weight and feed restriction did not have any measurable effects on work performance. Similar results were obtained in Mali (Khibe and Batholomew, 1990). These authors fed 3 groups of oxen either natural pastures (Group 1: control), natural pasture hay + urea (Group 2) or natural pasture hay + urea + 1 kg of cotton seed (Group 3). The dry season supplementation resulted in lower LW losses in oxen in group 2 (-100 g/day) than in the control group (-200 g/day). Oxen in group 3 gained weight (240 g/day). Despite these differences in LW changes all animals performed the same amount of work either ridging or weeding. Again in Mali, Dicko and Sangare (1984) studied the effect of supplementary feeding before work on work performance. They concluded that the work level was not high enough to show any beneficial effect of the supplementation on work performance since oxen were ploughing light sandy soils. They also suggested that dry season feed supplementation was necessary for oxen whose LW was going to be less than that required to perform work during the cropping season. Bartholomew, Khibe, Little and Ba (1993) attempted to determine the separate effects of LW and body condition on work performance. Unfortunately the relative effect of body weight and body condition could not be distinguished in their study because of the confounding effect of these two factors on the animals they used.

4.3. Experimental work : Effect of body condition prior to work and weight losses during work on work output

4.3.1. 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 weight 326 kg, were used. Oxen were housed as in Experiment 2 (Chapter 3). They were fed chopped millet stover *ad libitum*, supplemented with a concentrate mix made up of wheat bran (500 g/kg), groundnut cake (350 g/kg), rock phosphate (50 g/kg), crushed bone (50 g/kg) and common salt (50 g/kg). Ten g DM/kg $LW^{0.75}$ of this concentrate was fed each day. 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 (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 one 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 two oxen in groups 1, 2 and 3 were 615, 650 and 692 kg, respectively.

The experiment lasted 7 weeks. Teams of two animals worked 4 days each week. Work consisted of pulling a loaded sledge around a flat circuit. Each day, the teams of two oxen worked for 4 h to complete ten 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 the ergometer was used to measure work performed, distance travelled and elapsed working time for different known loads. A regression line 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 12.5 kgf/100 kg live weight (LW). The following equation was used to determine work loads:
$\text{Load (kg)} = 0.201 \times \text{Force(N)} - 7.44$.

Animals were allowed to stop for 3-4 min after each lap. Time needed to travel the circuit, 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, feed allowances and refusals were weighed and a feed sample taken, dried and ground for laboratory analysis.

At the end of the 7 weeks of work, 10 animals were used to investigate the rate of weight gain after work. These animals grazed rainy season natural pastures from

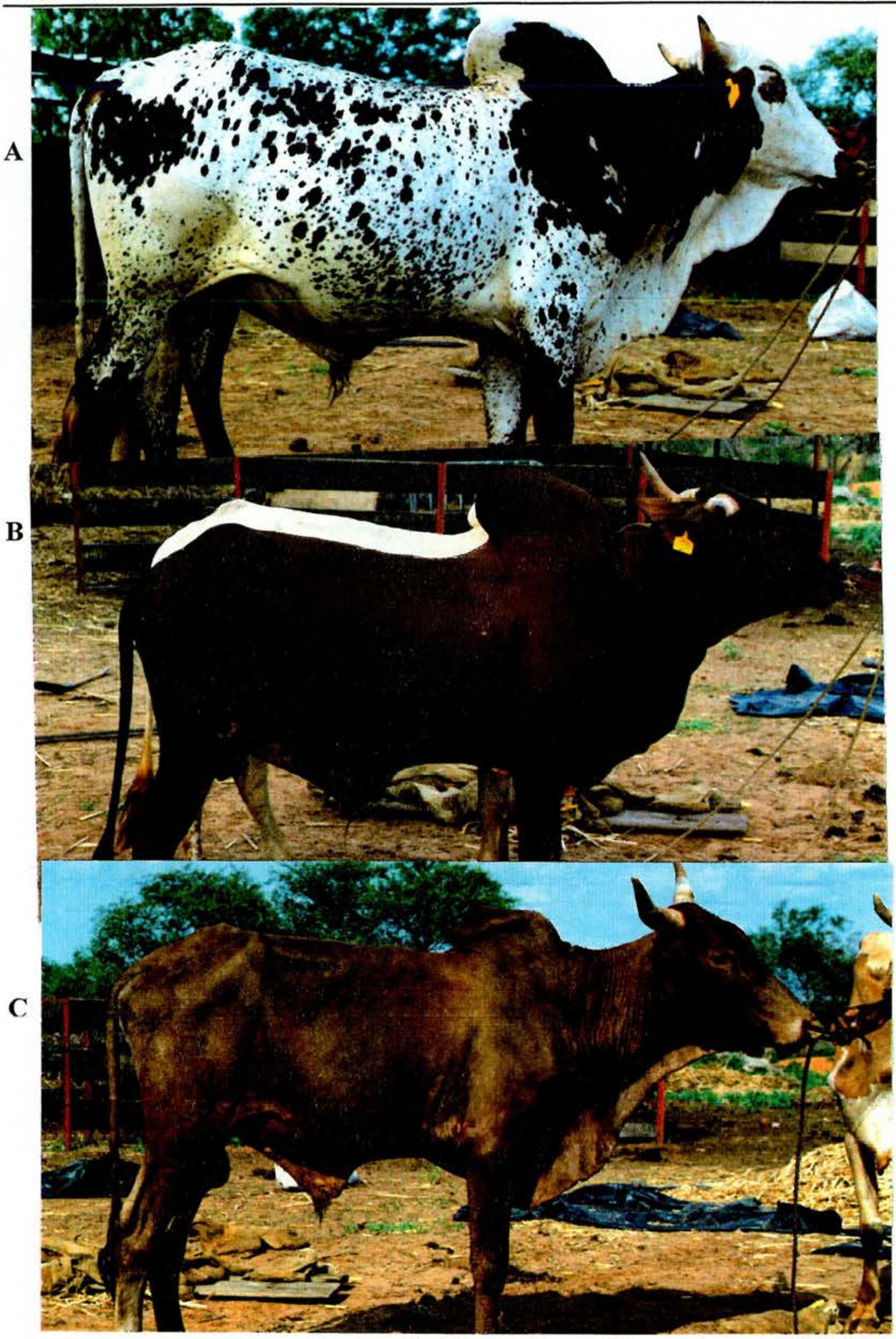


Plate 4. ***Examples of oxen in 'good' (A), 'medium' (B) and 'poor' (C) initial body condition used to investigate the effect of body condition prior to work on work output***

08:30 to 17:00 hours without supplementation. They were kept in stables after grazing and had access to water *ad lbitum*. LW was measured every second day in the morning before grazing for 2 months.

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 oxen 17 and 25. Teams 3 and 6 were excluded in the analysis of speed, power and work output. Statistical models used to analyse feed intake, weight change, body condition, speed, power and work output are detailed as follows:

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

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

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 LW)

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

where:

Y = one observation of daily feed 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 feed intake, weight change, speed, power and work over time.

4.3.2. Results.

Intake of millet stover.

The 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 LW; g/d/ kg $LW^{0.75}$) were significant (Table 17). Oxen in 'poor', 'medium' and 'good' IBC consumed 75.14 (±1.08), 72.94 (±1.07) and 64.78 (±0.93) g/d/ kg $LW^{0.75}$, 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. The interaction between week and IBC or activity was not significant. Feed intake on working and non-working days were similar.

Change in live weight and body condition.

Differences in daily weight gain due to IBC were significant (P<0.01). All oxen lost weight during this experiment, but weight losses were highest in oxen in 'good' IBC. Daily weight losses were 456 (±103.3), 308 (±103.3) and 719 (±89.5) g/day for oxen in 'poor', 'medium' and 'good' IBC, respectively. Weight losses averaged 21.90, 14.78 and 34.51 kg over 7 weeks. These weight losses are equivalent to 7.4, 4.7 and 9.9% of the initial live weight for oxen in 'poor', 'medium' and 'good' IBC.

Table 19.
Mean (± s.e.) daily intake (g/ kg LW and g/ kg $LW^{0.75}$) of millet stover by 18 oxen in 'poor', 'medium' or 'good' initial body condition (IBC) pulling 12.5 kgf/100 LW 4h/day, 4 days/week for 7 weeks (Experiment 4).

Sources of variation	Daily feed intake g/kgLW	Daily feed intake g/kg$LW^{0.75}$	Significance
Initial Body condition			Linear*
'Poor'	18.1 ± 0.26	75.1 ± 1.08	
'Medium'	17.2 ± 0.26	72.9 ± 1.07	
'Good'	15.2 ± 0.22	64.8 ± 0.93	
Activity			NS
Rest	17.2 ± 0.20	72.2 ± 0.86	
Work	16.6 ± 0.19	69.7 ± 0.79	
Week			Linear *** Quad. ***
1	13.8 ± 0.22	58.1 ± 0.94	
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, LW: live weight, Quad.: quadratic

The second degree polynomial regression of daily weight gains on the interaction between body condition and week was significant (P<0.05). Weight losses were significantly larger in oxen in 'good' IBC than in oxen in 'poor' or 'medium' IBC. Weight losses estimated from polynomial regressions are illustrated in Figure 3. 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 declined for all oxen 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.

After work stopped 10 of the oxen used in this experiment had access to natural pastures of good quality without supplementation. Rapid weight gains were observed as illustrated by the following regression equations of LW (kg) on time (60 days(D) after work):

$LW = 257(\pm 12) + 0.825(\pm 0.054) \times D$ for oxen in 'poor' IBC,

$LW = 302(\pm 12) + 0.967(\pm 0.041) \times D$ for oxen in 'medium' IBC,

$LW = 303(\pm 11) + 0.870(\pm 0.037) \times D$ for oxen in 'good' IBC.

The overall rate of change of LW was similar irrespective of the IBC score. However when LW change was expressed relative to the initial LW of oxen, oxen in 'poor' and 'medium' IBC had higher LW gains (3.20 g/d/kgLW) than oxen in 'good' IBC (2.87 g/d/kgLW). 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 LW.

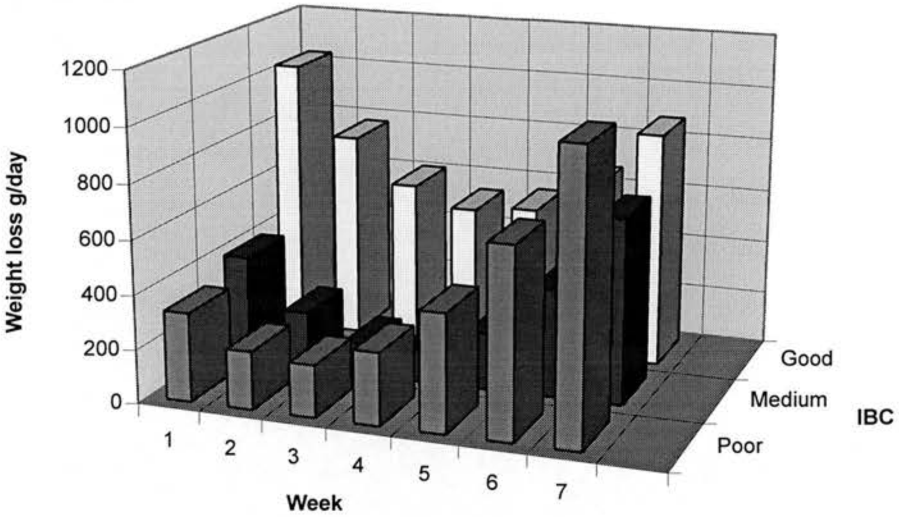


Figure 3.
Live weight losses over 7 weeks of work for oxen in poor, medium and good initial body condition (IBC) during Experiment 4.

Speed and power.

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 LW), the effect of IBC was no longer significant. There was no significant difference in work output, speed, power and force of 3 teams which had similar initial live weight (719, 721 and 739 kg respectively) and had 'poor', 'medium' and 'good' IBC, respectively (Table 21).

Table 20.
Mean speed (m/s) and power (W and W/100 kg LW) by 9 ox teams in 'poor', 'medium' or 'good' initial body condition (IBC) pulling 12.5 kgf/100 LW 4h/day, 4 days/week for 7 weeks (Experiment 4).

Source of variation	Speed (m/s)	Power (W)	Power (W/100kg LW)
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			
1	0.95	706	117
2	0.97	722	120
3	0.97	724	120
4	0.95	706	117
5	0.92	690	115
6	0.92	685	114
7	0.89	666	111
8	0.88	654	109
9	0.87	651	108
10	0.87	646	107
s.e.	0.08	6	1
Week			
1	0.78	590	95
2	0.84	631	103
3	0.88	653	107
4	0.98	725	120
5	1.00	744	124
6	0.96	713	120
7	0.99	739	126
s.e.	0.07	5	1

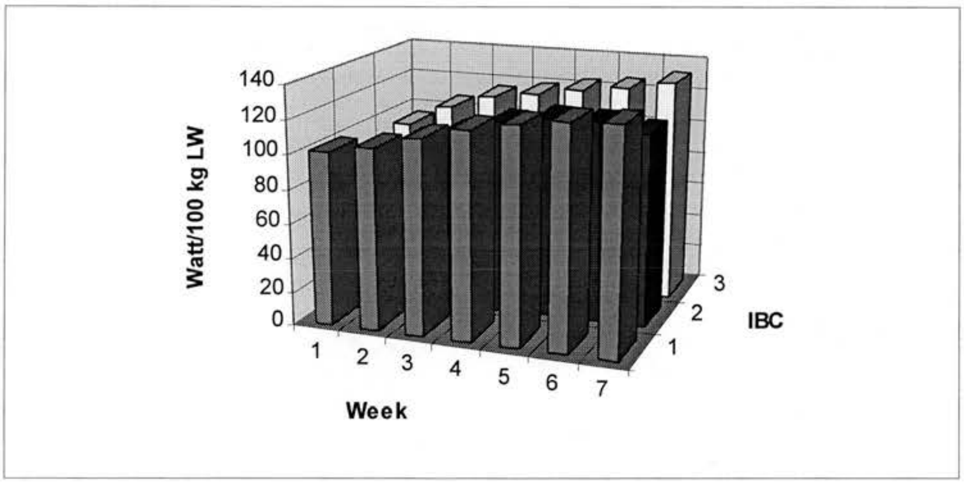
W: Watt, LW: live weight

Differences in speed and power output due to week were significant ($P<0.01$) (Table 20 and Figure 4). Speed and power output increased steadily over weeks for all teams irrespective of their IBC. Even though oxen lost 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 are seen 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 round a steady decline in speed and work output of 0.014 m/s and 10.3 W were observed for each lap completed.

Figure 4.
Power output (W/100 kg LW, graph A; W, graph B) over 7 weeks of work for oxen in good (3), medium (2) and poor (1) initial body condition (IBC) (Experiment 4)

A



B

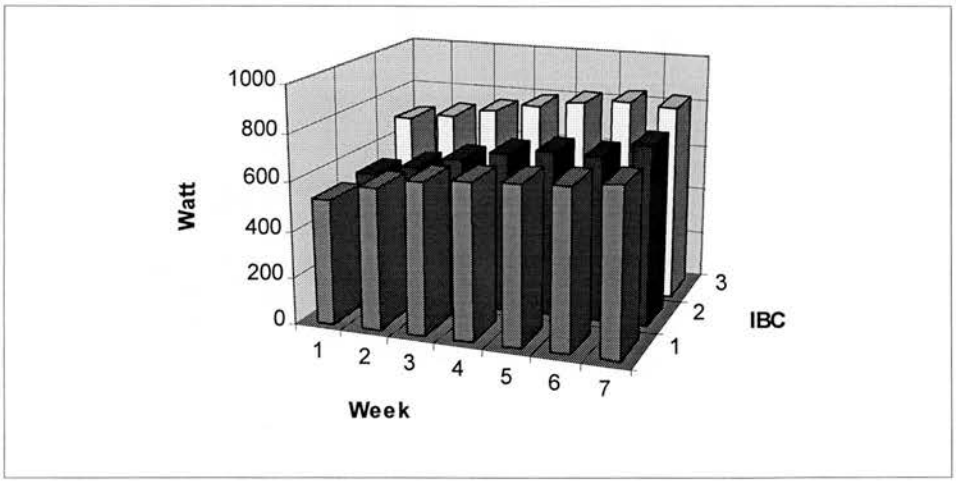


Table 21.
Work output, distance travelled, initial live weight, walking speed, draught force and power for 3 teams of similar live weightan and in 'poor', 'medium' and 'good' initial body condition (IBC) (Experiment 4).

	Team in 'Poor' IBC	Team in 'Medium' IBC	Team in 'Good' IBC
Initial live weight (kg)	719	721	739
Distance travelled (m/day)	9417	8450	9600
Work done (kJ/day)	8262	7437	7876
Walking speed (m/s)	0.89	0.79	0.90
Force (N)	870	881	822
Power(W)	775	697	741

kJ: kilojoule, m/s: metre/second, N: Newton, W: Watt

.

Work output

IBC was a significant source of variation (P<0.01) of draught force exerted, but did not affect distance travelled each day during work. There was a significant (P<0.01) linear increase of daily work output as IBC was better. Table 22 shows mean force exerted, distance travelled and work output. Since there was no significant difference in distance travelled, the superior work performance of teams in 'good' IBC as compared to teams in 'poor' and 'medium' IBC, is therefore attributed to differences in force exerted. Teams in 'good' IBC were able to generate higher forces than oxen in 'medium' or 'poor' IBC. Consequently, the team's live weight was responsible for

Table 22.
Mean daily draught force (N) exerted, distance (m) travelled and work output (kJ) by 9 ox teams in 'poor', 'medium' or 'good' initial body conditionIBC pulling 12.5 kgf/100 LW 4h/day, 4 days/week for 7 weeks (Experiment 4).

	Force	Distance	Work
Initial body condition			
'poor'	682	9355	6386
'medium'	741	9262	6851
'good'	818	9310	7610
s.e.	2	187	148

superior work performance of oxen in 'good' IBC. Each day, work output of teams in 'good' IBC exceeded work output of teams in 'poor' and 'medium' IBC by 0.76 and 1.22 MJ, respectively.

Energy balance

Oxen in all body condition groups exhibited a negative energy balance (Table 23). The calculated and the oserved live weight change agreed well.

Table 23.

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 LW 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 = **$(a\times b\times (0.53\times(LW/1.08)^{0.67}))\times c$** (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 as found in chapter 2, Efficiency of doing work = 0.32

4: 1 kg weight change ≡ 15 MJ NE.

4.3.3 Discussion

Feed intake and adaptation to work

Results from this experiment showed that work did not affect intake of millet stover. Oxen worked 4 days a week and feed intakes by animals during working and non-working days were compared whereas in the results reported in chapter 3 feed intakes during working or non-working periods were compared. The absence of an effect of work on intake of millet stover was consistent for all experiments. It was also apparent, from this experiment, that poor body condition before work was conducive to higher intake of millet stover over 7 weeks. This increase in feed intake may be the response of oxen that underwent a period of feed restriction prior to work followed by periods of work when a concentrate supplement was fed.

The steady increase of feed 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 appetite. Bartholomew, Khibe and Little (1994) also attributed increases in speed of working teams over time to an adaptation to work. Working the animal during the dry season has the advantage that oxen are fit when cropping starts and they do not have to undergo this adaptation period.

Live weight, body condition and work performance

During the preparation phase of the experiment oxen were fed to reach the targeted body condition and live weight. This was however difficult to achieve because 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 LW and IBC on the rate of work (W) in different treatment groups, power output was expressed relative to LW (W/100kg LW). The use of power relative to LW 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 LW than oxen in 'poor' or 'medium' IBC.

Power is a function of draught force and speed. During the present experiment, power output expressed in W was higher for oxen in 'good' IBC than for oxen in 'poor' or 'medium' IBC. Since the walking speed was similar for all working teams irrespective of their body condition, the superiority of oxen in 'good' IBC was assumed to be associated with their high draught force that is, in turn, determined by LW. The effect of IBC on power output was no longer significant when power output was expressed relative to LW. The similarity of power output relative to LW for all oxen, suggests that animals with same body mass, irrespective of its fat content, generated the same power output. This is supported by the fact that oxen in good condition did not outperform oxen with equal LW but in poor body condition (Table 22).

Work output was higher for oxen in 'good' IBC than for oxen in 'poor' or 'medium' IBC. The daily distance travelled was similar for all oxen irrespective to their IBC. This, with the fact that draught force was set to be equivalent to 12.5 kgf/100 kg LW in this experiment , suggests that the better work output of oxen in 'good' IBC was again due to the higher draught force they exerted and consequently to their higher LW. This gives further evidence that work output was more dependant on live weight than on body condition.

To evaluate the relative importance of body weight and body condition on work performance, Bartholomew *et al.* (1994) applied 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. Live weight is the single most important determinant of work output. Therefore, as recommended by Bartholomew *et al.* (1994), farmers should be encouraged to select large-framed animals for draught purposes.

Oxen in 'poor' and 'medium' IBC sustained average draught forces of 682 and 741 N, respectively. These animals might not be able to perform ploughing or ridging for extended periods because doing these two activities requires 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 LW change and power output were reported by Bartholomew *et al.*(1993). It is therefore apparent that the weight losses oxen can tolerate before work output is affected are difficult to set. Oxen were able to perform work as long as they had to do so. However, continuous and severe weight losses can compromise the health of the animal, or even its life, and are not acceptable.

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

CHAPTER V

IMPLICATIONS OF HEAT STRESS ON DRAUGHT OXEN

5.1. Introduction

The capacity of mammals to maintain a relatively constant body temperature despite wide ranges of environment temperature is referred to as homeostasis (Brody, 1945). Homeostasis depends on the equilibrium between the amounts of heat the animal produces metabolically, heat gains from and heat losses to the environment. Metabolic processes yield energy which is used for synthesis of new molecules, for work and/or is liberated as heat. In a mature animal at rest most of the energy is used to support basal metabolism, but an ox, working at a steady rate, e.g. ploughing, uses nutrients to generate energy in the form of ATP at 6 to 10 times the rate at rest (Preston and Leng, 1987). Only part of this energy is used by muscles and the rest is released as heat (Upadhyay, 1989). This excess heat must to be dissipated by various physiological processes for the ox to maintain homeostasis.

Heat exchange between the animal and its environment involves heat gains from solar radiation when the animals is exposed to the sun. Radiant solar absorption is influenced by the animal coat colour (Finch, 1986; McDowell, 1972). For instance, cattle with white hair have solar reflectivity of around 50%, while those with red or brown hair reflect about 20%, and those with black, only 10% (Curtis, 1983). In addition, Finch (1986) found that in *Bos indicus* cattle, the inward flow of heat at the skin of black steers is 16% larger than for brown steers and 58% larger than for white ones.

Animals lose heat through non-evaporative or sensible processes (radiation, conduction and convection) and through evaporative processes such as sweating and panting (Yousef, 1987). The relative importance of these heat loss avenues is dependent upon environmental temperatures and species of animals. When animals are in the thermoneutral or comfort zone, temperature regulation is achieved by non-evaporative physical processes alone. Metabolic rate is also at minimum in the thermoneutral zone (Bligh and Johnson, 1973). The upper bound of the thermoneutral zone is the upper critical temperature above which thermoregulatory evaporative heat loss processes of a resting thermoregulatory animal are recruited (Bligh and Johnson, 1973). The draught oxen has to accommodate high heat loads resulting from increased muscle activity and heat gains from solar radiation. Because of the high ambient temperatures prevailing in the semi-arid tropics, non-evaporative cooling mechanisms are likely to be no longer effective because they require a temperature gradient between the animal and the environment. Evaporative cooling mechanisms therefore become the main route of heat dissipation in draught oxen working in these areas. Panting and sweating are unlikely to be sufficient to enable the ox to dissipate its excess heat load. As a result, it is expected that body temperature of working oxen will rise continuously when ambient temperatures are high. This results in hyperthermia during long periods of work. During prolonged work for 3-4 h in hot dry or hot humid conditions the rectal temperature of work animals may reach 42-43 ^{o}C associated with muscle temperature of 44-45 ^{o}C (Upadhyay, 1989).

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

There are two approaches to analyse the effects of environmental stress on animal performance and physiology (Webster, 1983). The first approach involves correlation whereas the second involves causation between variables. Although the correlation approach may not distinguish between direct and indirect effects, its advantage lies in its potential for strength in numbers. The causation approach is based on classic experimental designs with controlled variables, for instance ambient temperature or relative humidity in climate rooms. It can yield firm conclusions. However, physiological experiments conducted in laboratory settings will not usually simulate validly changing environmental circumstances in the field. For instance, the effects of important environmental factors such as wind speed and solar radiation that affect thermoregulatory mechanisms, are not taken into account in these types of laboratory experiments. Finch (1986) pointed out that the effect of heat stress on body temperature of cattle in a climate room may differ markedly from that measured in a natural radiant environment. This is because radiation increases sweat gland activity due to local heating effects at the neuroglandular junction (Finch, 1986). The correlation approach is used in this chapter to investigate the physiological implications of heat stress on draught oxen and the effects of working under hot conditions on work performance of draught oxen. Some aspects of the physiological responses to heat stress such as changes in plasma thyroid hormone concentrations and alterations in water consumption were dealt with in Chapter 3. This chapter will therefore examine physiological changes related to body temperature and respiration rate of draught oxen working under hot conditions.

5.2. Material and methods

Data on physiological parameters reported here were obtained during Experiments 2, 3 and 4. Details of these experiments, i.e., the animals and their feeding management, the experimental designs and the work routine are given in Chapter 3 for Experiments 2 and 3 and in Chapter 4 for Experiment 4. This section will report the measurements of rectal temperature and respiration rate of draught oxen that were carried out during these experiments. A brief summary of the experimental settings is however necessary.

During Experiment 2, 18 oxen were used. They were fed millet stover and a concentrate (21.3 g/kgLW$^{0.75}$). Oxen were allotted to 3 treatment groups: 1: rest, 2: work for 2 h/day and 3: work for 4 h/day (2 h in the morning and 2 h in the afternoon). Oxen at-rest were exposed to solar radiation when other teams were working. This experiment lasted 9 weeks divided into three 3-week periods, from July to August 1993. Oxen worked pulling a loaded sledge or weeding cereal crops.

In Experiment 3, 12 oxen were allotted to 3 treatment groups: 1: rest, 2: work for 2.5 h/day and 3: work for 5 h/day (2.5 h in the morning and 2.5 h in the afternoon). This experiment was carried out between December 1993 and February 1994 for 10 weeks divided into 2-week periods. In both experiment 2 and 3 treatments were applied in sequence during 2-week or 3-week experimental periods.

In Experiment 4, 18 oxen were allotted to 3 treatment groups according to their body condition and weight before work: 1: ‘poor’, 2: ‘medium’ and 3:‘good’ initial body condition. Animals worked 4 h/day (in the morning or in the afternoon), 4 days a week for 7 weeks. This experiment was conducted from July to September 1994. In both Experiments 3 and 4, oxen worked pulling a draught force proportional to their body weight (10 % in Experiment 3 and 12.5 % in Experiment 4).

5.2.1. Measurement of rectal temperature

Experiment 2. During this experiment rectal temperature was continuously monitored using a rectal probe. This device is made up of a stainless steel rode about 10 cm long in which is inserted a 5000Ω thermistor. The thermistor was connected to a 21X Campbell data logger which was programmed to measure temperature each second and to average and store temperatures each min. The procedures used to monitor rectal temperature with thermistors and data logging system are detailed in Appendix 10.

The data logger was carried in a backpack harnessed to the oxen. This data logging system allowed the continuous measurement of rectal temperature for any activity performed by the animals. However, since two sets of equipment were available, they were alternated between the 4 teams of oxen that were working each day. Clinical thermometers were used to monitor changes in rectal temperatures of oxen at-rest. After each work session data stored in the datalogger were downloaded to a computer using the Campbell 21X data transfer program.

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

5.2.2. Measurement of respiration rate

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

5.2.3. Climate data

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

5.2.4. Data analysis

Experiment 2

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

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

where T_{db} and T_{dp} are dry-bulb and dew-point temperatures respectively. T_{dp} was estimated as the difference between dry-bulb and wet-bulb temperatures (T_{wb}) (Du Preez *et al.*, 1990). A psychrometric chart with metric units (Curtis, 1983) was used to derive an equation estimating T_{wb} given observed values for ambient temperatures and relative humidity (RH):

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

The extent and rate of heat stress were assessed in this experiment by fitting second degree polynomial curves of rectal temperature on time in min. The polynomial coefficients were then subjected to analysis of variance. Main sources of variation were team, treatment, period, week, time of the day, and 30-min working periods. THI was used as covariate. In further analyses THIs during work were grouped into 5 classes (class 1: THI<=70; 2: 71=<THI<=73; 3: 74<=THI<=76; 4: 77<=THI<=78; 5: THI>=79) and used as a main factor of variation in the analysis of variance of power output.

Experiment 3

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

Experiment 4

Differences in RR, MIRT and RT between individual oxen was tested using the Duncan test (SAS, 1985). The transformation $\log_e$ (RT- 37) (Turner, 1984) was used to control homogeneity of variance of RT. The repeatability of RT and MIRT were estimated as:[$(\sigma_a/(\sigma_a+\sigma_e)$] (Harvey, 1990) where σ_a is the variance component of the individual ox and σ_e is the residual component of variance. The statistical model used included body condition, ox nested within body condition and time of the day as main sources of variation. Lap number (1-10) was included as a covariate.

5.3. Results

5.3.1. Experiment 2

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 and maximum relative humidity 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

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

$$\text{WAM: } Y = 37.75 + 0.033025 \times T - 1.3878 \times 10^{-4} \times T^2 \qquad \text{(Equa. 1)}$$

$$\text{RAM: } Y = 37.90 + 0.007763 \times T - 1.153 \times 10^{-5} \times T^2 \qquad \text{(Equa. 2)}$$

$$\text{WPM: } Y = 38.53 + 0.0360018 \times T - 1.7604 \times 10^{-4} \times T^2 \qquad \text{(Equa. 3)}$$

$$\text{RPM: } Y = 38.77 + 0.012605 \times T - 6.627 \times 10^{-5} \times T^2 \qquad \text{(Equa. 4)}$$

where Y = rectal temperature and T = time in min.

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

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

Table 24 shows the relationship between work rate, rectal temperature and THI. Work rate was significantly affected by time of the day ($P<0.05$) and 0.5 h intervals of time during work ($P<0.01$), rectal temperatures ($P<0.01$) and THIs ($P<0.01$). Work rate was higher in the morning (108±3.2 W/100 kgLW) than in the afternoon (88±3.8 W/100 kgLW).

5.3.2. Experiment 3

This experiment was conducted during the coolest period in the year in Niger, from December to February. Minimum, maximum and mean ambient temperatures when animals were working were 17, 30 and 24 °C, respectively, in the morning and 26, 34 and 30 °C, respectively, in the afternoon. There was a gradual increase in RT and RR during work either in the morning or in the afternoon, but RT and RR were highest during the afternoon working sessions (Table 25). When oxen worked in the morning, their speed increased during the first hour of work and then declined until the last lap when they walked faster because they were heading towards the stables. During the afternoon working sessions, the working speed declined continuously from the start of work.

Table 24.
Work rate, change in rectal temperature (MIRT, initial rectal temperature was 37.75 °C in the morning and 38.53 °C in the afternoon) and Temperature Humidity Index (THI) for each 0.5 h time interval during work in the morning and in the afternoon (Experiment 2)

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

5.3.3. Experiment 4

Average ambient temperatures and relative humidity were 24 °C and 82% respectively when oxen worked in the morning from about 9:00 to 13:00 hours. Average ambient temperature and relative humidity were 30 °C and 73% respectively, when work took place in the afternoon from 14:00 h to 18:00 hours.

The animals' physiological responses to THI and work are illustrated in Figure 5 for RR and in Figure 6 for RT. Patterns of changes of THI and power output of oxen working for 4 h in the morning or in the afternoon are showed in Figure 7. THI increased gradually during work either in the morning or in the afternoon. Average THIs were higher in the afternoon (80) than in the morning (77).

THI increased from 74 when work started in the morning at about 9:00 hours to 79 at the end of work at about 13:00 hours. In the afternoon, THI increased during the first part of work from 79 to reach a maximum of 80 on average at about 15:45 hours. THI remained constant afterwards for 2 h until about 17:30 hours before they started to decrease at a small rate until the cessation of work at about 18:00 hours.

Table 25.
Rectal temperature (RT), respiration rate (RR) and working speed of oxen working 2.5 h in the morning or in the afternoon (Experiment 3)

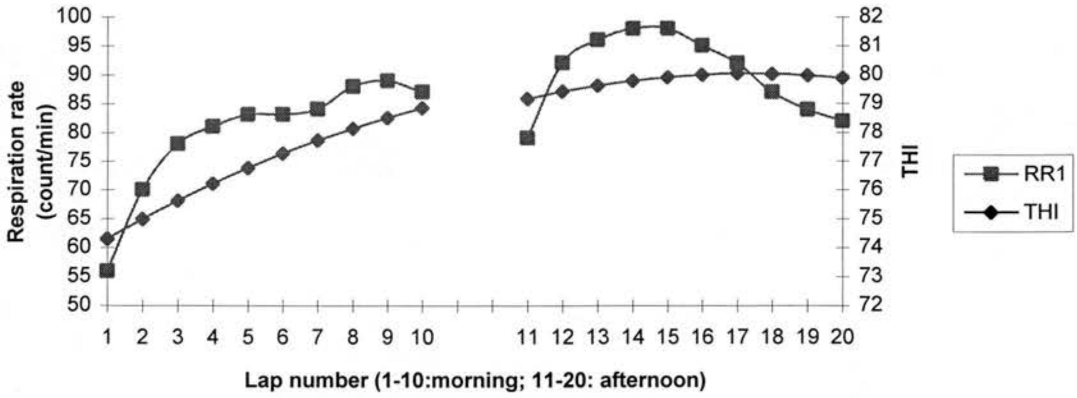
Distance travelled (km)	RT (°C)	RR (count/min)	Speed (m/s)
Morning			
1 km	37.8	36	0.92
2 km	38.1	37	0.91
3 km	38.5	47	0.99
4 km	38.6	51	0.97
5 km	38.9	56	0.85
6 km	39.3	61	0.93
s.e.	0.13	3	0.03
Afternoon			
1 km	38.9	59	0.93
2 km	39.3	66	0.89
3 km	39.6	78	0.83
4 km	39.8	82	0.85
5 km	39.9	86	0.87
6 km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

Mean RR in the morning (74±4 counts/min) was lower ($P<0.01$) than in the afternoon (89±4 counts/min) but the pattern of change was different. RR increased gradually in the morning with a parallel increase in THI. The highest RR in the morning was recorded at the 9th lap after about 3.75 hours of work. In the afternoon RR increased during the first hour of work to reach a maximum at the 4th lap at about 1.7 h after work started. The following decrease in RR occurred when THI became constant or declined. This period coincided with a marked decrease in the work rate

The pattern of changes in RT was similar to that of THI either in the morning or in the afternoon. Mean RT was higher in the afternoon (39.9 ± 0.02 ^{o}C) than in the morning (39.4±0.02 ^{o}C), ($P<0.01$). Also the highest RT was reached earlier in the afternoon (4th lap) than in the morning (9th lap). RT before work was higher and MIRT lower in the afternoon (38.4±0.09 and 2.5±0.16 ^{o}C) than in the morning (37.8±0.09 and 2.8 ±0.16 ^{o}C). Body condition had a significant effect on the MIRT ($P<0.05$). The extent of increase in RT was larger for oxen in 'good' condition (MIRT=3.01±0.13) than for oxen in medium (2.39±0.11) or oxen in 'poor' condition (2.11±0.11).

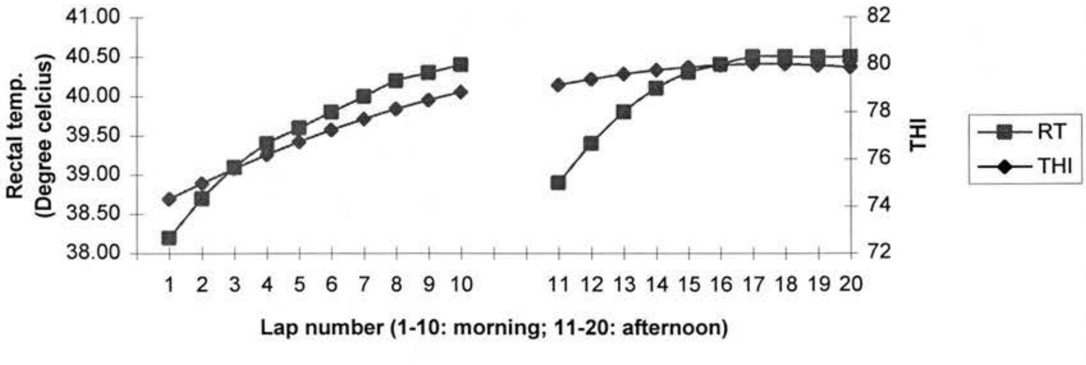
Table 26 shows the mean RT before work and during work, MIRT and RR for oxen pulling a loaded sledge around a circuit during Experiment 4. The oxen used in this experiment fit into 3 groups according to the above parameters. The first group include oxen 6, 16 and 17 with high RT, MIRT and RR. The second group is composed of oxen with the lowest values for these parameters (oxen 10, 12, 14 and 1). The third group is made up of oxen with inconsistent or intermediate values of RT, MIRT and RR. The first group seems to show more pronounced signs of heat stress than the second group. A marked difference between the first and the second group was their body condition. The animals in the first group had a better body condition on average than animals in the second group.

Figure 5. Change in temperature humidity index (THI) during work and respiration rate (RR1), recorded after each lap, of oxen working for 4 hours (10 laps around a circuit) either in the morning (lap 1-10) or in the afternoon (lap 11-20), Experiment 4.



Respiration rate was recorded after animals completed each lap. Values are averages for 18 animals which worked 4 h/day, 4 days/week for 7 weeks.

Figure 6. Change in temperature humidity index (THI) during work and rectal temperature (RT) of oxen working for 4 h (10 laps around a circuit) either in the morning (lap 1-10) or in the afternoon (lap 11-20), Experiment 4.



Rectal temperature was recorded after animals completed each lap. Values are averages for 18 animals which worked 4 h/day, 4 days/week for 7 weeks.

the onset of the cropping season because cropping tasks are not delayed by lack of fitness of oxen when they resume work.

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

Heat stress inhibits work performance. Options to reduce heat stress include working animals in the coolest periods of the day, allowing them to rest and providing water between bouts of work. The provision of shade during resting periods is also worthwhile. Observations from this study suggest that the number of hours worked per day should be split between morning and afternoon sessions. Oxen should be worked for a total for 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 given water to help them cool down.

6.6. Future research

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

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

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

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

The use of the Oxylog and the Ergometer allowed significant progress to be made on the nutrition of working animals. Their energy requirements are known more precisely. However there is still a need to accumulate more information on the energy expenditure and work performance of animals working on different soil types using different implements. For instance, the uptake by farmers of soil and water conservation techniques in the semi-arid areas will require more research on the draught forces and therefore animal live weight required and on their nutrient requirements to perform tasks such as ridging and tied-ridging on soils of different type.

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

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

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

There was steady improvement of power output as work progressed despite live weight losses incurred by oxen. There is therefore a need for further research to investigate the optimum level of work load required during the dry season to ensure oxen are fit for work at the onset of the cropping season.

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

REFERENCES

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

AGRICULTURAL RESEARCH COUNCIL (1980). *The Nutrient Requirements of Ruminant Livestock.* Commonwealth Agricultural Bureaux, Slough.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS (1990). *Official Methods of Analysis of the Association of Analytical Chemists.* 15th ed. Association of Analytical Chemists, Virginia, USA.

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.

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

BACCARI, F., JOHNSON, H.D. and HAHN, G.L. (1983). Environmental heat effects on growth, plasma T_3 and post-heat compensatory effects on Holstein calves. *Proceedings of the Society Exp. Biol. Med.*, **173**, 312-318.

BACKRIE, B., MURRAY, R.M. and HOGAN, J.P. (1988). The effect of work on intake and rumen fluid volatile fatty acids and NH3 concentrations, of steers fed Rhodes grass hay. *DAP Bulletin,* **7**, 9-13.

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. and FfOULKES, D. (1988). Effect of work and level of feed intake on nutritional parameters and body weight change of swamp buffalo cows. *DAP Project Bulletin,* **7**, 2-7.

BAMUALIM, A., FfOULKES, D. and FLETCHER, I.C. (1987). Preliminary observations on the effect of work on intake, digestibility, growth and ovarian activity of Swamp buffalo cows. *DAP Project Bulletin,* **3**, 6-10.

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.

BARTON, D. (1987). *Draught Power Supply, Nutrition and the Work Output of Draught Animals in Bangladesh.* Report prepared for the Ford foundation, Dhaka and FSRDP. Bangladesh Agricultural University, Mymensingh.

BARTON, D. and SAADULLAH, M. (1987). Draught animal power and nutrition in Bangladesh. *Draught Animal News*, **7**, 16-17.

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. Hohenheim University.

BLAXTER, K. (1989). *Energy Metabolism in Animals and Man.* Cambridge University Press, 336 p.

BLIGH, J. and JOHNSON, H.D. (1973). Glossary of terms for animal physiology. *Journal of Applied Physiology,* **35**, 941-961.

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. (Eds: Blaxter, K.L.), pp. 441-443. EEAP Publication **No. 11.** Academic Press, London.

BUVANENDRAN, V., ADAMU, A.M. and ABUBAKAR, B.Y. (1991). Heat tolerance of zebu and Friesian-zebu crosses in the Guinea savannah zone of Nigeria. *Tropical Agriculture (Trinidad),* **69**, 394-396.

CAMPLING, R.C. and LEAN, I. (1983). Food characteristics that limit voluntary intake. In: *Nutritional Physiology of Farm Animals*. (Eds: Rook, J.A.F. and Thomas, P.C.), pp. 457-475.Longman, London,

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.

CLAR, U. (1991). *Entwichlung einer Feldmethode zur Messung des Energie Umsatzes bei Zugtieren.* PhD thesis, University of Hohenheim.

COLBURN, M.W., EVANS, J.L. and RAMAGE, C.H. (1968). Ingestion control in growing ruminant animals by the components of cell-wall constituents. *Journal of Diary Science,* **51**, 1458-1464.

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: McDowell, L.R.). Academic Press, Orlando, London.

CONRAD, H.R., PRATT, A.D. and HIBBS, J.W. (1964). Regulation of feed intake in dairy cows.1. Change in importance of physical and physiological factors with increasing digestibility. *Journal of Diary Science,* **47**, 54-62.

CTVM. (1987): *Ergometer Instruction Manual.* University of Edinburgh.

CURTIS, S.E. (1983). *Environmental Management in Animal Agriculture.* Iowa State University. Ames, Iowa.

DICKO, M. (1983). Nutrition animale: Materiel et méthodes. In: *Recherches sur les Systémes des Zones Arides du Mali: Résultats Préliminaires.* (Eds: Wilson, R.T., de Leeuw, P.N. and de Hann, C.), pp 95-96. Centre International pour l'Elevage en Afrique, Addis Abeba (Ethiopia).

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.

DIJKMAN, J.T. (1993). *The measurement of draught ruminant energy expenditure in the field.* Ph.D. Dissertation, University of Edinburgh, Edinburgh.

DU PREEZ, J.H. GIESECKE, W.H and HATTINGH, P.J. (1990). Heat stress in dairy cattle and other livestock under Southern African conditions. I. Temperature-humidity index mean values during the four main seasons. *Onderstepoort Journal of Veterinary Research*, **57**, 77-87.

EGAN, A.R. (1989). Living with, and overcoming limits to, feeding value of high fibre roughages. In: *Draught Animals in Rural Development*. (Eds: Hoffman, D., Nari, J. and Patheram, R.J.). pp. 176-180. Proceedings of an International Research Symposium, Cinapas, Indenosia, 3-7 July 1989. ACIAR Proceedings Series no. **27**. ACIAR. Canberra.

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.

FAO. (1972). *Manual on the Employment of Draught Animals in Agriculture*. FAO, Rome, Italy.

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

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*. (Eds: Journet, M., Grenet, E., Farce, M-H., Theriez, M. and Demarquilly, C.). pp. 95-120. Proceedings of the Ivth International Symposium on the Nutrition of Herbivores. INRA Editions, Paris.

FELIUS, M. (1985). *Genus Bos: Cattle Breeds of the World*. Rahway, USA; MSDAGvet, 234 p.

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

FfOULKES, D. and BAMUALIM, A. (1989). Supplementary feeds: Their effects on performance of draught animals and their acceptability to Southeast Asian farmers. In: *Draught Animals in Rural Development*. (Eds: Hoffmann, D., Nari, J. and Petheram, R.J.). pp. 134-145. Proceedings of an International Research Symposium, Cinapas, Indenosia, 3-7 July 1989. ACIAR Proceedings **No. 27.** Canberra.

FINCH, V.A. (1986). Body temperature in beef cattle: Its control and relevance to production in the tropics. *Journal of Animal Science,* **62**, 531-542.

FORBES, J.M. (1986). *The Voluntary Food Intake of Farm Animals*. Butterworths. 205p.

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

FRISCH, J.E. (1981). Changes occurring in cattle as a consequence of selection for growth rate in a stressful environment. *Journal of Agricultural Science (Cambridge),* **96**, 23.

GOE, M.R. and McDOWELL, R.E. (1980). *Animal Traction, Guidelines to Utilisation*. Cornell International Agriculture Mimeo. Ithaca, N.Y. Cornell University.

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.

HARMAN, N.G. and PETHICK, D.W. (1994). The effects of sustained exercise on gluconeogenesis, glycogenolysis and glycogen synthesis in Merino sheep. *Australian Journal of Agricultural Research,* **45**, 1189-1202.

HARVEY, W.R. (1990). User's Guide for LSMLMW and MIXMDL.

HIERNAUX, P., CISSÉ, M.I. and DIARRA, L. (1983). Les paturages naturels. In: *Recherches sur les Systémes des Zones Arides du Mali: Résultats Préliminaires.* (Eds: Wilson, R.T. and de Leeuw, P.N.), pp. 33-42. Centre International pour l'Elevage en Afrique, Addis Abeba (Ethiopia), 189p.

HORNICKE, H., EHRLEIN, H.J., TOLKMITT, G., NAGEL,M., EPPLE, E., DECKER, D., KIMMICH, H.P. and KREUZER, F. (1974). Method for continuous oxygen consumption measurements in exercise horses by telemetry and electronic data processing. In: Proceedings of the 6th Symposium on Energy Metabolism of farm Animals. (Eds: Menke, K.H. Lantzsch, H.J. and Reichl, I.R.), pp. 257-260. EAAP Publication **No. 14**, Juris, Zurich.

HOWELL, P.J. and O'NEILL, D.H. (1989). *ILCA contract report, Document OD/90/05.* AFRC Engineering Overseas Division, Silsoe, U.K.

JAHNKE, H.E. (1982). *Livestock Production Systems and Livestock Development in Tropical Africa.* Kiel, FRG: Kieler Wissenschaftverlag Vauk. 473 p.

JOHNSON, H.D. (1982). Role of physiology in cattle production in the tropics. In: *Animal Production in the Tropics.* (Ed: Yousef, M.K.). 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: Johnson, H.D.). pp. 35-57. Elsevier, Amsterdam.

KARTIARSO, D., MARTIN, D. and TELENI, E. (1987). Nutritional studies using a treadmill at James Cook University. *DAP Bulletin,* **3**, 11-15.

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.* (Eds: Lawrence, P.R., Lawrence, K., Dijkman, J.T. and Starkey, P.H.). pp. 175-179. Proceedings of the Fourth Workshop of the West Africa Animal Traction Network held in Kano, Nigeria, 9-13 July 1990. Published on the behalf of the West Africa Animal Traction network by the International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

KLAIJ, M.C. and SERAFINI, P.G. (1988): The potential impact of the use of animal traction on millet-based cropping systems in the Sahel. In: *Animal Traction for Agricultural Development*. (Eds: Starkey, P. and Faye, A.). pp. 422-431. Workshop of the West Africa Animal Traction Network held 7-12 July 1988, Saly, Senegal Published on behalf of the West Africa Animal Traction Network by the Technical Centre for Agricultural an Rural Cooperation (CTA), Ede-Wageningen, The Netherlands. CTA.

LAWRENCE, P.R. (1985). A review of the nutrient requirements of draught oxen. In: *Draught Animal Power for production.* (Ed: Copland, J.W.). pp. 59-63. Proceedings of an International Workshop Held at James Cook University, Townsville, Qld, Australia, 10-16 July 1985. ACIAR Proceedings Series **No 10.** 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.* (Eds: Becker, K., Lawrence, P.R. and Orskov, B.). pp. 101-121. Proceedings of an International workshop held on September 24 1994 at the Institute for Animal production in the Tropics and Sub-Tropics, University of Hohenheim, Germany. Universitat Hohenheim.

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., 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 jointly organised by the International Atomic Energy Agency and the Food and Agricultural Organisation of the United Nations and held in Vienna, 15-19 April 1991. International Atomic Energy Agency, Vienna.

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. 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.

LAWRENCE, P.R. and ZERBINI, E. (1993). Recent trends in research on draught animal nutrition. In: *Human and Draught Animal Power in crop production.* (Eds: O'Neill, D.H. and Hendriksen, G.), pp. 40-49. Proceedings, Silsoe Research Institute/CEC/FAO Workshop, Harare, Zimbabwe, January 18-22. FAO, Rome.

LHOSTE, P. (1987). *L'Association Agriculture-Elevage. Evolution du Systeme Agropastoral au Sine Saloum (Sénégal).* IEMVT . 314 pages.

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.* (Eds: K. Becker, P. Lawrence and B. Orskov). pp.127-130. Proceedings of an International workshop held on September 24 1994 at the Institute for Animal production in the Tropics and Sub-Tropics, University of Hohenheim, Germany. Universitat Hohenheim

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 ^{o}C. *Journal of Agricultural Science (Cambridge),* **113**, 211-222.

MATHERS, J.C. and OTCHERE, E.O. (1993). Research on the nutrition of working animals: needs, experiences and methods. In: *Research for Development of Animal Traction in West Africa.* (Eds: Lwarence, P.R., Lawrence, K., Dijkman, J.T. and Starkey, P.H.). pp. 163-174. 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, Addis Abbaba, Ethiopia.

MATTHEWMAN, R.W. and DIJKMAN, J.T. (1993). The nutrition of ruminant draught animals. *Journal of Agricultural Science (Cambridge),* **121**, 297-306.

MATTHEWMAN, R.W., DIJKMAN, J.T. and ZERBINI, E. (1993). The management and husbandry of male and female Draught animals: Research achievements and needs. In: *Research for Development of Animal Traction in West Africa.* (Eds: Lwarence, P.R., Lawrence, K., Dijkman, J.T. and Starkey, P.H.). pp. 125-132. 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, Addis Abbaba, Ethiopia.

MATTHEWMAN, R.W., OLDHAM, J.D. and HORGAN, G.W. (1993). A note on the effect of sustained exercise on straw intake and body weight in lactating cattle. *Animal Production*, **57**, 491-494.

MAYER, J., MARSHALL, N.B. VITALE, J.J., CHRISTENSEN, J.H. MASHAYEKHI, M.B. and STARE, F.J. (1954). Exercise, food intake and body weight in nnormal rats and genetically obese adult mice. American Journal of Physiology, **177**: 544

MAYET, Y. (1990). *Remote sensing of body temperature in dairy cows.* PhD Thesis. University of Newcastle.

McDONALD, P., EDWARDS, R.A. and GREENHALGH, J.F.D. (1981). *Animal Nutrition.* Third Edition. Longman, London, 479 p.

McDOWELL, R.E. (1972). *Improvement of Livestock Production in Warm Climates.* W.H. Freeman and Company, San Francisco. 711 p.

McLEAN, J.A. and TOBIN, G. (1987). *Animal and Human Calorimetry.* Cambridge University Press. New York. 338 p.

MONTGOLFIER-KOEVI, C. and VLAVONOU, A. (1981). *Trends and Prospects for Livestock and Crop Production in Tropical Africa.* ILCA Working Document **No. 5**. ILCA, Addis Ababa, Ethiopia.

MUNZINGER, P. (1982). *Animal Traction in Africa.* Eschborn. 490 p.

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.

NIELSEN, B. (1992). Heat stress causes fatigue! Exercise performance during acute and repeated exposures to hot, dry environments. In: *Muscle Fatigue Mechanisms in Exercise and Training.* (Eds: Marconnet, P., Komi, P.V., Saltin, B., Sejersted, O.M.). *Medical Sport Science*, **34**: 207-217. Basel, Karger

O'NEILL, D.H. (1989). Instrumentation for the measurement of draught animal performance. *ILCA Bulletin,* **33**, 2-8.

ORTON, R.K., HUME, I.D. and LENG, R.A. (1985). Effects of level of dietary protein and exercise on growth rates of horses. *Equine Veterinary Journal*, **17**, 381-385

OSBOURN, D.F. (1974). The utilisation of natural grasslands in the tropics. In: *Beef Cattle Production in Developing Countries.* (Ed: Smith, A.J.). Proceedings of the Conference held in Edinburgh from the 1st to 6th September 1974 organised by the Centre for Tropical Veterinary Medicine. University of Edinburgh, Centre for Tropical Veterinary Medicine.

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

PEARSON, R.A. (1985). Physiological change associated with work: Some lessons from the horse. In; *Draught Animal Power for Production.* (Eds: Copland, J.W.). pp. 51-56. Poceedings of an International Symposium Workshop Held at James Cook University, Townsville, Qld, Australia 10-16 July 1985. ACIAR Proceedings **No. 10.**

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

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 Nutritional 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.

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

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. (1984). Supplementation of diets based on fibrous residues and by-products. In: *Straw and other fibrous by-products as feed.* (Eds: Sundstol, F. and Owen, E.). pp. 373-413. Elsevier, Amsterdam.

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.

REED, J.D. (1992). Sorghum and millets as forage crops in the semi-arid tropics. In: *Utilization of Sorghum and Millets.* (Eds: Gomez, M.I.; House, L.R.; Rooney, L.W. and Dendy, D.A.V.). pp. 173-178. ICRISAT, Patancheru, India.

REED, J.D., KEBEDE, Y. and FUSSELL, L.K. (1988). Factors affecting the nutritive value of sorghum and millet crop residues. In*: Plant Breeding and the Nutritive Value of Crop Residues.* (Eds: Reed, J.D., Capper, B.S. and Neate, P.J.H.). pp. 233-249. Proceedings of a Workshop held at ILCA, Addis Ababa, Ethiopia 7-10 December 1987. ILCA, Addis Ababa, Ethiopia.

REH, I. (1981). Etude de la production de viande de bovins de trait dans le Sine Saloum. Comparaison de quelques paramétres de production entre les bovins de trait et bovins de troupeaux. Institut de Production Animale. Université Technique de Berlin.

RIBEIRO, J.M. DE C.R., BROCKWAY, J.M. and WEBSTER, A.J.F. (1977). A note on the energy cost of walking in cattle. *Animal Production*, **25**, 107-110.

SCHLECHT, E., SANGARÉ, M. and BECKER, K. (1994). Feed intake of zebu cattle grazing Sahelian pastures in the dry and rainy season. In*: Sustainable Small- scale Ruminant Production in Semi-arid and Sub-humid Tropical Areas.* (Eds: Becker, K., Lawrence, P., Orskov, B.). pp. 31-37. Proceedings of an International Workshop held on September 24 1994 at the Institute for Animal Production in the Tropics and Sub-Tropics, University of Hohenheim. Universitat Hohenheim.

SENE, M., GARIN, P. (1990). Le travail à la dent sur sol gravillonaire au Sénégal. In: *Animal Traction for Agricultural Development.* (Eds: Starkey, P. and Faye, A.). pp. 218-223. Proceedings of the Third Workshop of the West Africa Animal Traction Network Held 7-12 July 1988, Saly, Sénégal. Published on behalf of the West Africa Animal Traction Network by the Technical Centre for Agricultural and Rural Cooperation (CTA), Ede-Wageningen, The Netherlands.

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.

SOUTH, F.E. (1961). Phrenic nerve- diaphragm preparations in relation to temperature and hibernation. *American Journal of Physiology*, **200**, 565-571.

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

STATISTICAL ANALYSIS SYSTEMS (SAS). (1985). SAS User's Guide. Statistics. SAS Institute Inc., Cary, NC, USA.

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

TELENI, E. and HOGAN, J.P. (1989). Nutrition of draught animals. In: *Draught Animals in Rural Development.* . (Eds: Hoffman, D., Nari, J. and Patheran, R.J.). pp. 118-133. Proceedings of an International Research Symposium, Cipanas, Indonesia, 3-7 July 1989. ACIAR Proceedings **No 27**, Canberra.

THEANDER, O. and AMAN, P. (1984). Anatomical and chemical characteristics. In: *Straw and other Fibrous By-products as Feed.* (Eds: Sundstol, F. and Owen, E.). pp. 45-78. Elsevier, Amsterdam.

THOMAS, C.K. and PEARSON, R.A. (1986). Effect of ambient temperature and head cooling on energy expenditure, food intake and heat tolerance on Brahman and Brahman Friesian cattle working on treadmills. *Animal Production*, **43**, 83-90.

THORNE, P.J. and CARLAW, P.M. (1992). Stover quality in pearl millet. *Tropical Agriculture (Trinidad),* **69,** 191-193.

TURNER, H.G. (1984). Variation in rectal temperature of cattle in a tropical environment and its relation to growth rate. *Animal Production*, **38**, 417-427.

UPADHYAY, R.C. (1989). Performance limiting factors in draught animals*: Can they be manipulated to improve output? In: Draught* Animals in Rural Development. (Eds: Hoffman, D., Nari, J. and Patheran, R.J.), pp. 166-175. Proceedings of an International Research Symposium, Cipana, Indonesia, 3-7 July 1989ACIAR Proceedings No 27, Canberra.

VAN SOEST, P.J. (1983). *Nutritional Ecology of the Ruminant*. O & B Books, Inc., Corvalis, Oregon. 374 p.

VAN SOEST, P.J. (1995). *Nutritional Ecology of the Ruminant*. Second edition ed. Cornell University Press, Ithaca. 476p.

VAN THU, N. (1994). *A study of the use of female cattle and buffalo crushing sugar cane in Colombia*. M.Sc. Thesis, Swedish University of Agricultural Sciences, Uppsala.

WEBB, P. and TROUTMAN, S.J. (1970). An instrument for continuous measurement of oxygen consumption. *Journal of Applied Physiology*, **28**, 867-871.

WEBSTER, A.J.F. (1983). Environmental stress and the physiology, performance and health of ruminants. *Journal of Animal Science*, **57**, 1584-1593.

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

WHIRELAW, F.G., BROCKWAY, J.M. and REID, R.S. (1991). Measurement of carbon dioxide production is sheep by isotope dilution. *Quarterly Journal of Experimental Phsiology*, **57**, 37-55.

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.

YOUNG, B.A. (1970). Application of the carbon dioxide entry rate technique in the measurement of energy expenditure by grazing cattle. In: *Energy metabolism of farm animals*. (Eds: Schurch, A. and Wenk, C.). pp. 237-241. Proceedings of the fifth Symposium on Energy Metabolism, Zurich, Switherland (EAAP Publication **No. 13**), EAAP, Juris and Verlag, Zurich.

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

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.

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.

APPENDICES

Appendix 1. Live weight, standing metabolic rate, oxygen consumption of oxen standing still in the shade.

Animal	Live weight kg	Standing metabolic rate kJ/kgLW$^{0.75}$	O_2 consumption l/min	O_2 consumption l/min/kgLW$^{0.75}$	O_2 consumption l/min/kgLW
4	341	509	1.35504	0.017076	0.003974
4	344	520	1.39344	0.017445	0.004051
4	326	579	1.49025	0.019424	0.004571
9	536	451	1.68546	0.01513	0.003145
9	525	355	1.30622	0.01191	0.002488
9	546	381	1.44373	0.012782	0.002644
10	303	481	1.17191	0.016137	0.003868
10	282	579	1.33670	0.019424	0.00474
10	286	516	1.20390	0.017311	0.004209
10	282	429	0.99040	0.014392	0.003512
10	284	473	1.09778	0.015868	0.003865
10	298	456	1.09722	0.015298	0.003682
13	328	464	1.19975	0.015566	0.003658
13	294	571	1.36008	0.019156	0.004626
13	310	453	1.12276	0.015197	0.003622
13	299	447	1.07827	0.014996	0.003606
13	324	438	1.12215	0.014694	0.003463
13	329	568	1.47202	0.019055	0.004474
16	383	489	1.42028	0.016405	0.003708
16	385	410	1.19549	0.013755	0.003105
16	378	573	1.64794	0.019223	0.00436
16	368	668	1.88291	0.02241	0.005117
16	378	421	1.21079	0.014124	0.003203
16	386	496	1.44907	0.01664	0.003754
16	391	416	1.22714	0.013956	0.003138
16	354	522	1.42919	0.017512	0.004037
16	367	477	1.34179	0.016002	0.003656
16	375	462	1.32079	0.015499	0.003522
21	400	447	1.34128	0.014996	0.003353
21	382	424	1.22908	0.014224	0.003217
21	384	425	1.23681	0.014258	0.003221
21	388	429	1.25820	0.014392	0.003243
21	365	516	1.44556	0.017311	0.00396
21	401	429	1.28968	0.014392	0.003216
21	368	602	1.69687	0.020196	0.004611
21	401	394	1.18446	0.013218	0.002954
21	393	436	1.29106	0.014627	0.003285
24	398	497	1.48572	0.016673	0.003733
24	370	486	1.37548	0.016304	0.003718
24	403	484	1.46047	0.016237	0.003624
24	357	490	1.35010	0.016439	0.003782
24	384	415	1.20771	0.013922	0.003145
24	368	436	1.22897	0.014627	0.00334
24	364	484	1.35313	0.016237	0.003717
24	390	459	1.35138	0.015399	0.003465

Appendix 2.1. Live weight, energy cost of walking and walking speed on ground surfaces of different consistencies (0: unploughed sandy soils, 1: ploughed sandy soils 2: laterite track)

Animal	Live weight (kg)	ground surface	Energy cost of walking J/m/kg	Walking speed (m/s)
13	299	1	1.81	0.76
10	282	1	1.80	0.78
4	341	1	2.22	0.78
10	284	1	1.85	0.80
24	364	1	2.07	0.81
24	370	1	1.79	0.81
21	382	1	2.83	0.85
13	310	1	1.97	0.87
16	378	1	1.89	0.88
13	294	1	2.18	0.89
24	368	1	1.58	0.89
4	341	0	1.69	0.89
21	382	0	2.17	0.89
10	286	1	1.45	0.90
4	344	0	1.59	0.90
10	284	0	1.25	0.91
24	370	0	1.29	0.92
13	294	0	1.39	0.94
21	368	0	1.24	0.94
4	326	1	1.79	0.96
10	282	0	1.33	0.96
10	282	1	1.95	0.96
24	368	0	1.21	0.97
13	299	0	1.28	0.97
24	364	0	1.34	0.97
10	286	0	1.18	0.98
16	378	0	1.32	0.98
16	354	1	1.54	0.99
10	282	0	1.31	0.99
16	367	1	1.81	0.99
21	368	1	1.67	1.00
13	310	0	1.34	1.00
21	365	1	2.08	1.01
4	326	0	1.63	1.05
24	357	1	1.74	1.05
16	391	2	1.04	1.06
24	398	2	1.25	1.07
21	365	0	1.52	1.08
16	354	0	1.36	1.10
16	367	0	1.23	1.10
13	328	2	0.94	1.10
24	357	0	1.35	1.11
16	368	0	1.70	1.11
16	368	1	2.10	1.11
16	385	2	1.32	1.13
21	401	2	1.15	1.13
13	324	2	1.14	1.16
10	298	2	0.89	1.17
16	378	2	1.08	1.18

Appendix 2.1. continued

24	390	2	1.21	1.23
16	375	2	1.13	1.24
21	388	2	1.26	1.27
16	383	2	1.34	1.28
21	393	2	1.33	1.28
21	384	2	1.32	1.29
16	386	2	1.25	1.31
24	403	2	1.49	1.37
21	400	2	1.34	1.42
10	303	2	1.44	1.44
13	329	2	1.83	1.45

Appendix 2.2. Analysis of variance of the standing metabolic rate (SMR)

```
          Class   Levels   Values

          OX         7   4 9 10 13 16 21 24

          Number of observations in data set = 44

            General Linear Models Procedure

Dependent Variable: SMR
                        Sum of          Mean
Source            DF        Squares        Square  F Value    Pr > F

Model              7    56280.31808    8040.04544     2.44    0.0376

Error             36   118829.31828    3300.81440

Corrected Total       43   175109.63636

          R-Square         C.V.      Root MSE          SMR Mean

          0.321400     12.06759     57.45271         476.090909

General Linear Models Procedure

Dependent Variable: SMR

Source            DF      Type I SS   Mean Square  F Value     Pr > F

OX                 6    39496.80581    6582.80097     1.99    0.0921
WT                 1    16783.51227   16783.51227     5.08    0.0303

Source            DF    Type III SS   Mean Square  F Value     Pr > F
```

OX	6	25064.96440	4177.49407	1.27	0.2975
WT	1	16783.51227	16783.51227	5.08	

Appendix 2.3. SAS Programme for the analysis of variance of the energy cost of walking

```
DATA WALK;
INFILE 'C:\DATANAL\EXPMT4\WALK2.TXT';
INPUT DAT AN LW TER EW SPD;
PROC GLM;
CLASS AN TER;
MODEL EW=AN TER LW SPD;
TEST H=TER E=AN;
LSMEANS AN TER/STDERR;
MEANS AN TER/DUNCAN;
RUN;
```

Appendix 2.4. Analysis of variance of the energy cost of walking

General Linear Models Procedure

Dependent Variable: Energy cost of walking (J/m/kg)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Animal	5	0.95485346	0.19097069	3.93	0.0044
Surface	2	3.34031004	1.67015502	34.38	0.0001
LW	1	0.43224726	0.43224726	8.90	0.0044
Speed	1	0.17041397	0.17041397	3.51	0.0669

Tests of Hypotheses using the Type III MS for Animal as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Surface	2	3.34031004	1.67015502	8.75	0.0233

Appendix 3.1. Efficiency of ploughing (Activity 1), pulling a loaded cart (load = 300 kg: activity 21; load = 600 kg: activity 22; load = 900 kg: activity 23), and force, power and speed during work.

Animal	Live weight (kg)	Activity	Efficiency of doing work	Power (W)	Force (N)	Speed (m/s)
21	401	23	0.59	731	569	1.29
21	384	22	0.58	462	408	1.13
13	329	21	0.53	466	379	1.23
21	384	23	0.5	623	544	1.15
21	401	23	0.49	741	571	1.3
21	401	22	0.48	583	459	1.27
21	401	21	0.43	410	325	1.26
16	378	21	0.43	327	290	1.13
21	388	21	0.4	366	283	1.29
16	368	1	0.4	1042	1079	0.97
24	384	21	0.39	339	297	1.14
24	368	1	0.37	704	944	0.75
10	303	23	0.37	611	509	1.2
24	403	21	0.36	442	334	1.32
10	303	22	0.36	476	380	1.25
21	393	21	0.35	273	436	1.26
13	324	21	0.35	292	281	1.04
24	370	1	0.34	750	1017	0.74
21	400	23	0.34	750	537	1.4
21	400	22	0.34	602	435	1.38
21	400	21	0.34	468	336	1.39
13	324	23	0.34	529	454	1.16
24	398	23	0.33	644	521	1.24
24	403	22	0.33	571	431	1.33
24	366	1	0.33	919	1265	0.73
21	368	1	0.33	998	1104	0.9
13	294	1	0.33	659	743	0.89
24	398	21	0.32	408	331	1.23
24	364	1	0.32	773	982	0.79
24	390	21	0.32	349	298	1.17
24	390	22	0.32	495	430	1.17
24	384	23	0.32	597	489	1.22
21	382	1	0.32	1212	1301	0.79
16	378	23	0.32	585	508	1.15
16	367	1	0.32	897	994	0.9
13	310	1	0.32	932	1145	0.81
24	398	22	0.31	496	411	1.21
24	384	22	0.31	481	387	1.24
16	378	22	0.31	521	415	1.26
24	390	23	0.3	525	490	1.07
21	365	1	0.3	836	1007	0.83
16	383	23	0.3	648	490	1.32
16	383	22	0.3	552	415	1.33
16	354	1	0.3	615	926	0.66
13	324	22	0.3	432	370	1.17
13	299	1	0.3	775	1081	0.72
10	282	1	0.3	723	1024	0.71
16	378	1	0.29	1130	1368	0.83
13	328	22	0.29	456	405	1.13

Appendix 3.1. continued

13	328	23	0.29	477	474	1.01
10	282	1	0.29	663	906	0.73
16	386	23	0.28	537	463	1.16
16	385	22	0.27	574	474	1.21
16	385	21	0.27	389	328	1.19
16	386	21	0.27	411	309	1.33
10	284	1	0.27	820	1183	0.69
16	368	1	0.26	1030	1226	0.84
16	375	22	0.26	483	394	1.23
16	386	22	0.25	463	368	1.26
16	375	23	0.25	623	503	1.24
10	286	1	0.25	653	606	1.08
16	383	21	0.24	392	276	1.42
16	375	21	0.24	326	261	1.25
13	328	21	0.24	346	287	1.2
16	391	23	0.23	689	553	1.24
16	391	22	0.22	505	404	1.25
10	298	21	0.22	331	271	1.22
10	298	23	0.22	644	537	1.2
16	391	21	0.21	382	302	1.26
10	298	22	0.21	462	385	1.2

Appendix 3.2. SAS Programme used to analyse the efficiency of doing work

```
DATA ENERG;
INFILE 'C:\DATANAL\expmt4\EXP.TXT';
INPUT DAT OX WT TER EF PW FRCE SPD;
PROC GLM;
CLASS OX TER;
MODEL EF = OX TER WT SPD TER*SPD;
LSMEANS OX TER/STDERR;
TEST H=TER E=OX;
RUN;
```

Appendix 3.3. Analysis of variance of the efficiency of doing work

General Linear Models Procedure

Dependent Variable: (Efficiency of doing work: EF)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
OX	4	0.13879767	0.03469942	7.79	0.0001
TER	3	0.01474385	0.00491462	1.10	0.3556
WT	1	0.00016030	0.00016030	0.04	0.8503
SPD	1	0.00612440	0.00612440	1.37	0.2460
SPD*TER	3	0.01331559	0.00443853	1.00	0.4014

Appendix 3.3. continued

Tests of Hypotheses using the Type III MS for OX as an error term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TER	3	0.01474385	0.00491462	0.14	0.9299

Appendix 4. Daily dry matter intake (DMI) by oxen working 0, 2 and 4 h/day (treatment 0, 2 and 4, Experiment 2)

Animal	Team	Period	Week	Treatment		Daily DMI (kg)	Daily DMI (kg/ kgLW)	Daily DMI (kg/kgLW$^{0.75}$)
10	1	1	3	0	1	4.30	16.72	66.96
3	1	1	1	0	1	3.65	15.91	61.92
3	1	1	3	0	1	3.18	13.96	54.25
10	1	1	2	0	1	4.22	16.53	66.11
3	1	1	2	0	1	3.77	16.19	63.24
10	1	1	1	0	1	4.11	16.23	64.78
10	1	2	2	4	1	4.59	18.17	72.46
10	1	2	3	4	1	4.59	18.13	72.33
3	1	2	1	4	1	3.38	15.15	58.56
3	1	2	2	4	1	3.52	16.02	61.70
10	1	2	1	4	1	4.11	16.05	64.22
3	1	2	3	4	1	3.72	16.84	64.97
10	1	3	3	2	1	4.74	18.49	74.02
3	1	3	1	2	1	3.89	17.46	67.48
10	1	3	2	2	1	4.55	17.92	71.56
3	1	3	2	2	1	3.91	17.52	67.71
10	1	3	1	2	1	4.69	18.28	73.16
3	1	3	3	2	1	4.08	17.72	69.06
12	2	1	1	2	1	4.18	15.32	62.25
1	2	1	3	2	1	3.99	15.05	60.73
12	2	1	3	2	1	4.78	17.45	71.02
1	2	1	2	2	1	4.03	15.32	61.72
1	2	1	1	2	1	3.93	15.24	61.09
12	2	1	2	2	1	4.81	17.51	71.32
12	2	2	1	0	1	4.52	16.39	66.80
12	2	2	2	0	1	4.45	15.83	64.84
1	2	2	1	0	1	4.18	15.78	63.68
1	2	2	2	0	1	3.6	13.51	54.61
1	2	2	3	0	1	4.49	16.6	67.36
12	2	2	3	0	1	4.46	15.58	64.12
12	2	3	1	4	1	4.3	15.1	62.02
1	2	3	1	4	1	3.97	14.72	59.67
12	2	3	3	4	1	4.92	17.98	73.13
1	2	3	2	4	1	4.03	15.5	62.24
12	2	3	2	4	1	4.43	16.23	66.00
1	2	3	3	4	1	4.14	16.2	64.8
8	3	1	1	4	1	3.41	16.84	63.55
13	3	1	3	4	1	4.06	15.72	63.04
8	3	1	3	4	1	3.73	17.84	67.87
13	3	1	2	4	1	3.88	14.95	60.01
13	3	1	1	4	1	4.2	16.3	65.32
8	3	1	2	4	1	3.62	17.47	66.31
8	3	2	3	2	1	3.98	18.35	70.47
13	3	2	2	2	1	4.13	15.79	63.51
8	3	2	1	2	1	3.68	17.13	65.59
8	3	2	2	2	1	3.39	15.61	59.92
13	3	2	3	2	1	4.07	15.7	63.01
13	3	2	1	2	1	4.33	16.57	66.63
8	3	3	3	0	1	4.22	18.31	71.36
13	3	3	3	0	1	4.24	15.53	63.15

Appendix 4 continued

13	3	3	2	0	1	4.27	15.79	64.03
8	3	3	2	0	1	3.85	17.01	66.00
13	3	3	1	0	1	4.04	15.29	61.69
8	3	3	1	0	1	4.15	18.62	71.97
2	4	1	2	0	2	4.07	15.71	63.06
2	4	1	1	0	2	4.02	15.56	62.39
11	4	1	3	0	2	4.69	15.89	65.88
11	4	1	1	0	2	4.57	15.72	64.93
2	4	1	3	0	2	4.16	15.9	63.96
11	4	1	2	0	2	4.78	16.15	67.00
11	4	2	3	4	2	4.6	16.28	66.77
2	4	2	3	4	2	4.4	16.73	67.36
11	4	2	2	4	2	4.63	16.6	67.84
2	4	2	2	4	2	4.04	15.66	62.76
2	4	2	1	4	2	4.24	16.33	65.55
11	4	2	1	4	2	4.76	16.62	68.40
2	4	3	2	2	2	4.1	15.19	61.57
11	4	3	3	2	2	4.99	17.04	70.49
2	4	3	1	2	2	4.61	17.13	69.39
11	4	3	1	2	2	4.92	17.03	70.24
11	4	3	2	2	2	4.71	16.35	67.40
2	4	3	3	2	2	4.91	18.06	73.35
6	5	1	3	4	2	4.34	15.93	64.72
9	5	1	3	4	2	4.28	14.87	61.26
9	5	1	2	4	2	4.24	15.08	61.76
6	5	1	2	4	2	4.64	16.91	68.84
9	5	1	1	4	2	3.93	14.04	57.46
6	5	1	1	4	2	3.88	14.12	57.50
9	5	2	3	2	2	4.13	14.18	58.60
9	5	2	1	2	2	4.57	15.72	64.93
6	5	2	1	2	2	4.65	17.27	69.98
6	5	2	3	2	2	4.43	16.13	65.65
9	5	2	2	2	2	4.06	13.91	57.53
6	5	2	2	2	2	4.43	16.3	66.21
9	5	3	1	0	2	4.61	15.75	65.15
6	5	3	2	0	2	4.75	16.87	69.14
9	5	3	3	0	2	4.58	15.44	64.10
6	5	3	1	0	2	4.69	16.84	68.83
9	5	3	2	0	2	4.38	14.98	61.99
6	5	3	3	0	2	5.12	17.84	73.44
16	6	1	2	2	2	4.98	17.07	70.55
16	6	1	1	2	2	4.37	15.18	62.52
14	6	1	1	2	2	4.97	18.71	75.54
16	6	1	3	2	2	4.9	16.69	69.10
14	6	1	2	2	2	5.27	19.62	79.45
14	6	1	3	2	2	5.11	18.83	76.45
16	6	2	2	0	2	4.65	15.67	65.05
16	6	2	3	0	2	4.62	15.41	64.13
14	6	2	2	0	2	5.1	18.56	75.59
16	6	2	1	0	2	4.86	16.54	68.49
14	6	2	3	0	2	5.24	18.74	76.66
14	6	2	1	0	2	5.61	20.61	83.73
14	6	3	1	4	2	5.44	19.39	79.37
14	6	3	2	4	2	5.39	19.49	79.51

Appendix 4 continued

16	6	3	2	4	2	4.53	15.33	63.57
16	6	3	3	4	2	4.63	15.85	65.53
16	6	3	1	4	2	4.86	16.18	67.35
14	6	3	3	4	2	5.48	19.79	80.75
17	7	1	1	4	3	4.81	14.77	62.77
4	7	1	2	4	3	5.36	17.66	73.73
4	7	1	3	4	3	5.61	18.39	76.87
17	7	1	2	4	3	5.05	15.44	65.68
17	7	1	3	4	3	5.15	15.42	65.93
4	7	1	1	4	3	4.98	16.66	69.29
17	7	2	1	2	3	5.32	15.85	67.83
4	7	2	1	2	3	5.87	19.15	80.14
17	7	2	2	2	3	5.25	15.6	66.83
17	7	2	3	2	3	5.37	15.84	67.99
4	7	2	3	2	3	5.88	19	79.70
4	7	2	2	2	3	5.49	17.82	74.69
17	7	3	1	0	3	5.35	15.53	66.94
4	7	3	2	0	3	5.73	17.6	74.79
4	7	3	1	0	3	5.78	18.18	76.79
17	7	3	2	0	3	5.1	14.67	63.38
4	7	3	3	0	3	6.07	18.31	78.16
17	7	3	3	0	3	5.59	15.91	68.90
89	8	1	3	2	3	5.5	13.23	59.75
89	8	1	2	2	3	5.69	13.72	61.91
88	8	1	2	2	3	5.25	11.73	53.98
88	8	1	1	2	3	4.93	11.09	50.94
88	8	1	3	2	3	5.44	12.22	56.15
89	8	1	1	2	3	5.11	12.41	55.89
89	8	2	1	0	3	5.41	13.1	59.09
88	8	2	3	0	3	4.69	10.5	48.30
89	8	2	2	0	3	5.57	13.25	60.02
88	8	2	1	0	3	4.8	10.91	49.99
89	8	2	3	0	3	5.7	13.51	61.26
88	8	2	2	0	3	4.55	10.23	47.00
69	9	1	1	0	3	5.16	11.8	53.99
100	9	1	2	0	3	5.65	13.18	60.00
100	9	1	3	0	3	5.6	12.95	59.05
100	9	1	1	0	3	5.27	12.41	56.36
69	9	1	2	0	3	5.65	12.81	58.72
69	9	1	3	0	3	5.24	11.91	54.55
69	9	3	2	4	3	5.12	12.1	54.90
100	9	3	1	4	3	5.35	12.7	57.58
69	9	3	3	4	3	5.33	12.57	57.06
69	9	3	1	4	3	5.13	12.35	55.77
100	9	3	2	4	3	5.17	12.32	55.78
100	9	3	3	4	3	5.91	14.06	63.68

Appendix 5.1. Daily dry matter intake by oxen working 0, 2.5 and 5 h/day during 3 experimental periods (period 1,2,3) lasting 2 weeks each (week 1,2) (Experiment 3)

Square	Animal	Team	Number of hour worked per day	Period	Week	Live weight (kg)	Daily DMI (g/kg LW)	Daily DMI (g/kg $LW^{0.75}$)
1	8	1	0	1	1	289	13.87	54.66
3	12	1	0	1	1	289	14.78	61.04
1	8	1	0	1	2	315	13.5	53.13
3	12	1	0	1	2	315	14.56	60.31
1	8	1	2.5	2	1	443	16.19	63.32
3	12	1	2.5	2	1	443	15.57	63.99
1	8	1	2.5	2	2	391	19.21	75.13
3	12	1	2.5	2	2	391	16.85	69.28
1	8	1	5	3	1	324	16.26	63.17
3	12	1	5	3	1	324	15.02	61.1
1	8	1	5	3	2	375	17.88	69.17
3	12	1	5	3	2	375	14.76	59.7
1	1	2	2.5	1	1	289	13.87	55.66
1	3	2	2.5	1	1	289	14.29	55.79
1	1	2	2.5	1	2	315	14.44	57.74
1	3	2	2.5	1	2	315	14.92	57.95
1	1	2	5	2	1	443	14.26	56.26
1	3	2	5	2	1	443	16.73	64.28
1	1	2	5	2	2	391	13.09	51.37
1	3	2	5	2	2	391	15.86	60.89
1	1	2	0	3	1	324	13.41	51.61
1	3	2	0	3	1	324	14.89	56.29
1	1	2	0	3	2	375	11.36	43.76
1	3	2	0	3	2	375	13.29	50.58
2	10	3	5	1	1	289	16.54	66.58
2	14	3	5	1	1	289	18.04	73.53
2	10	3	5	1	2	315	17.76	71.2
2	14	3	5	1	2	315	19.25	77.92
2	10	3	0	2	1	443	19.22	76.8
2	14	3	0	2	1	443	21.85	87.45
2	10	3	0	2	2	391	18.89	75.49
2	14	3	0	2	2	391	21.38	85.99
2	10	3	2.5	3	1	324	18.43	72.59
2	14	3	2.5	3	1	324	19.18	75.91
2	10	3	2.5	3	2	375	16.85	66.28
2	14	3	2.5	3	2	375	20.2	80.17
4	4	4	5	1	1	289	15.16	65.04
3	6	4	5	1	1	289	15.13	62.73
4	4	4	5	1	2	315	13.36	57.24
3	6	4	5	1	2	315	15.15	62.3
4	4	4	0	2	1	443	15.01	64.05
3	6	4	0	2	1	443	17.12	69.83
4	4	4	0	2	2	391	15.81	67.54
3	6	4	0	2	2	391	18.11	74.3
4	4	4	2.5	3	1	324	13.86	58.39

Appendix 5.1 continued

3	6	4	2.5	3	1	324	15.54	62.91
4	4	4	2.5	3	2	375	14.02	59.04
3	6	4	2.5	3	2	375	16.99	68.48
3	9	5	2.5	1	1	289	14.42	59.63
4	17	5	2.5	1	1	289	14.91	65.03
3	9	5	2.5	1	2	315	13.71	56.58
4	17	5	2.5	1	2	315	14.84	64.65
3	9	5	5	2	1	443	14.6	59.92
4	17	5	5	2	1	443	16.38	70.44
3	9	5	5	2	2	391	18.13	73.9
4	17	5	5	2	2	391	16.84	72.34
3	9	5	0	3	1	324	13.94	56.26
4	17	5	0	3	1	324	14.98	63.94
3	9	5	0	3	2	375	13.53	54.56
4	17	5	0	3	2	375	12.85	54.92
4	11	6	0	1	1	289	14.8	61.78
2	16	6	0	1	1	289	12.76	52.22
4	11	6	0	1	2	315	15.08	63.16
2	16	6	0	1	2	315	12.23	50.25
4	11	6	2.5	2	1	443	17.27	71.42
2	16	6	2.5	2	1	443	15.04	60.93
4	11	6	2.5	2	2	391	19.42	80.2
2	16	6	2.5	2	2	391	19.46	78.92
4	11	6	5	3	1	324	16.58	67.76
2	16	6	5	3	1	324	15.4	61.65
4	11	6	5	3	2	375	17.45	71.25
2	16	6	5	3	2	375	13.87	54.94

Appendix 5.2.SAS programme used to analyse intake of millet stover during Experiment 3

```
DATA INTAKE;
INFILE 'c:\datanal\expmt2\intake.prn';
INPUT SQR ANIM TEAM TRT PER WK LW ITK1 ITK2;
PROC GLM;
CLASSES SQR ANIM TEAM TRT PER WK;
MODEL ITK1 ITK2 = SQR ANIM(SQR) PER(SQR) TRT WK WK*TRT
WK*SQR WK*ANIM(SQR);
TEST H=TRT E=ANIM(SQR);
TEST H=WK E=WK*ANIM(SQR);
TEST H=WK*TRT E= WK*ANIM(SQR);
LSMEANS TRT WK WK*TRT/STDERR;
CONTRAST 'TRT L' TRT -1 0 1/E=ANIM(SQR);
RUN;
```

Appendix 5.3. Analysis of variance of intake of millet stover during Experiment 3.

```
                              General Linear Models Procedure
Dependent Variable: ITK1  (Daily DMI, g/kg LW)
Source            DF   Type III SS    Mean Square          F Value        Pr > F
SQR               3    770204.111      256734.704          24.50          0.0001
ANIM(SQR)         8   1290369.667      161296.208          15.39          0.0001
PER(SQR)          8    764070.567       95508.821          9.12           0.0001
TRT               2    148843.344      74421.672           7.10           0.0025
WK                1     12800.000      12800.000           1.22           0.2764
TRT*WK            2     70386.333      35193.167           3.36           0.0460
SQR*WK            3     11911.444        3970.481          0.38           0.7687
ANIM*WK(SQR)      8     83467.222      10433.403           1.00           0.4559

Tests of Hypotheses using the Type III MS for ANIM(SQR) as an error term Source

            DF     Type III SS    Mean Square  F Value      Pr > F
TRT         2      148843.3444   74421.6722          0.46   0.6462

Tests of Hypotheses using the Type III MS for ANIM*WK(SQR) as an error term Source

            DF     Type III SS    Mean Square           F Value       Pr > F
WK          1      12800.00000  12800.00000             1.23          0.3002


Tests of Hypotheses using the Type III MS for ANIM*WK(SQR) as an error term Source

            DF     Type III SS             Mean Square  F Value       Pr > F
TRT*WK      2      70386.33333             35193.16667          3.37  0.0866
```

Dependent Variable: ITK2 (Daily DMI, g/kg $LW^{0.75}$)

```
Source             DF   Type III SS     Mean Square          F Value      Pr > F
SQR                3   14927106.37     4975702.12            28.80        0.0001
ANIM(SQR)          8   18713294.33     2339161.79            13.54        0.0001
PER(SQR)           8   12408313.32     1551039.16            8.98         0.0001
TRT                2    2480250.90     1240125.45            7.18         0.0024
WK                 1     186762.35     186762.35             1.08         0.3054
TRT*WK             2    1047797.53      523898.76            3.03         0.0607
SQR*WK             3     187789.04     62596.35              0.36         0.7806
ANIM*WK(SQR)       8    1321629.44     165203.68             0.96         0.4846
```

Appendix 5.3 continued

Tests of Hypotheses using the Type III MS for ANIM(SQR) as an error term Source

	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	2	2480250.900	1240125.450	0.53	0.6078

Tests of Hypotheses using the Type III MS for ANIM*WK(SQR) as an error term Source

	DF	Type III SS	Mean Square	F Value	Pr > F
WK	1	186762.3472	186762.3472	1.13	0.3187

Tests of Hypotheses using the Type III MS for ANIM*WK(SQR) as an error term Source

	DF	Type III SS	Mean Square	F Value	Pr > F
TRT*WK	2	1047797.528	523898.764	3.17	0.0968

Dependent Variable: ITK1

Tests of Hypotheses using the Type III MS for ANIM(SQR) as an error term Contrast

	DF	Contrast SS	Mean Square	F Value	Pr > F
TRT L	1	104414.3361	104414.3361	0.65	0.4443

Dependent Variable: ITK2

Tests of Hypotheses using the Type III MS for ANIM(SQR) as an error term Contrast

	DF	Contrast SS	Mean Square	F Value	Pr > F
TRT L	1	1725156.225	1725156.225	0.74	0.4154

Appendix 6. SAS programme used to analyse intake of millet stover during Experiment 4

```
DATA INTAKE;
INFILE 'C:\DATANAL\EXPMT3\CHKDMI.PRN';
INPUT OX TM CND WK WRK I1 I2;
DATA INTAKE2; SET INTAKE; IF OX NE 17 THEN OUTPUT;
DATA INTAKE3; SET INTAKE2; IF OX NE 25 THEN OUTPUT;
WK2=WK*WK;
PROC GLM DATA=INTAKE3;
CLASS OX TM CND WK WRK;
MODEL I1 I2 = CND TM(CND) WRK CND*WRK WK WK*CND
WK*TM(CND);
CONTRAST 'POLYN COND' CND -1 0 1,
                      CND  1 -2 1;
CONTRAST 'L AND Q WEEK' WK -5 -3 -1 1 3 5,
                        WK 5 -1 -4 -4 -1 5/E=WK*TM(CND);

CONTRAST 'WK1 VS. OTHERS' WK -6 1 1 1 1 1 1/E=WK*TM(CND);
TEST H=WK2 E=WK*TM(CND);
TEST H=CND E=TM(CND);
TEST H=WRK E=TM(CND);
TEST H=WK E=WK*TM(CND);
TEST H=WK*CND E=WK*TM(CND);
TEST H=CND*WRK E=TM(CND);
LSMEANS CND WK WRK CND*WRK CND*WK/STDERR;
RUN;
```

Apendix 7. Digestibility coefficients of feed components for oxen working 0, 2.5 or 5 h/day during 3 experimental periods.

Animal	Team	Number of hours worked per day	Period	Square	DM	OM	ADF	NDF	HEM	ENERGY
8	1	0	1	1	28.8	49.5	48.5	29	52.9	39.2
12	1	0	1	3	29.1	45	43.7	33.6	48.8	34.9
6	4	5	1	3	30.2	50.5	47.9	30.2	56.7	42.3
3	2	2.5	1	1	32	48.2	46.6	33.5	52.6	37.8
1	2	2.5	1	1	34.6	46	43.5	38.7	52.8	42
10	3	2.5	3	2	35.6	52.1	46.1	39.7	62.2	49.4
16	6	0	1	2	35.7	53.7	54.5	38.1	53.1	46.3
10	3	5	1	2	36	50.3	47.2	38.5	57.6	44.3
14	3	5	1	2	36.2	45.8	46	40.8	46.4	41
11	6	0	1	4	38.2	49.6	48.5	40.6	53.1	41.4
4	4	5	1	4	38.3	51.4	51.3	39.8	52.7	45.4
17	5	2.5	1	4	40.2	52.1	49.7	45	57.4	42.5
9	5	2.5	1	3	42.5	56.5	55.8	43.8	59	46.7
14	3	2.5	3	2	44	58.8	53.7	46.9	68	53.2
16	6	5	3	2	44.1	62.7	57.9	48.4	71.2	53.4
17	5	0	3	4	44.2	60.3	55	48.2	70.4	55.2
8	1	2.5	2	1	44.4	59.2	55.7	46.2	65.1	50.2
9	2	5	2	1	44.8	64.7	58.5	48.3	74.7	54.1
1	2	5	2	1	44.9	57.7	53.2	47.8	65.6	49.8
3	5	0	3	3	45	60.3	55.3	50.3	69.5	49.9
11	3	0	2	2	45.3	57.7	54.6	47.5	62.9	49.2
14	5	5	2	4	45.3	60.1	55.8	46.6	68.1	51.1
17	6	5	3	4	45.4	64.3	59.7	48.1	71.9	56.8
3	2	0	3	1	45.6	59.4	52.4	50	69.7	50.2
1	2	0	3	1	46.2	64.6	57.4	50.2	74.1	57.6
11	6	2.5	2	4	46.7	57.6	53.3	48	65.1	48.7
6	4	2.5	3	3	47.3	58.7	55.4	51.2	64.4	49.5
10	3	0	2	2	47.4	59.9	55.8	49.3	67.3	52.9
12	1	2.5	2	3	48.3	64.6	62.3	50.3	69	55.7
8	1	5	3	1	48.5	61.1	57.7	52.2	67.1	56.5
9	5	5	2	3	49.4	64.1	60.9	51	69.7	54.8
6	4	0	2	3	49.7	63.4	62	51.7	65.6	55
4	4	0	2	4	50.4	61.8	57.7	52.9	68.6	53.9
12	1	5	3	3	50.5	66.4	60.2	52.9	76.8	57.9
4	4	2.5	3	4	51.4	64	60.5	55.1	70.2	57.8
16	6	2.5	2	2	52.6	66.8	65.9	53.6	67.9	59.9

Appendix 8. Time of first appearance of the marker (TT), mean retention time, rate constants k_1 and k_2 of digesta in the gastro-intestinal tract of oxen working 0, 2.5 or 5 hours/day (TRT)during 2 Experimental periods (Experiment 3).

Animal	Period	Team	TRT	Square	A1	A2	K1	K2	TT	MRT	1/K1	1/RK2
1	1	2	2.5	1	7.31	7.66	0.0237	0.0505	13.06	75.06	42.19	19.80
3	1	2	2.5	1	6.48	7.05	0.0145	0.0619	12.03	97.15	68.97	16.16
4	1	4	5	1	6.25	6.92	0.0143	0.0616	14.16	100.33	69.93	16.23
1	1	4	5	2	6.62	7.18	0.0208	0.0735	10.63	72.31	48.08	13.61
3	1	1	0	2	7.42	7.80	0.0208	0.0458	15.20	85.11	48.08	21.83
4	1	5	2.5	2	6.87	8.02	0.0192	0.0622	26.74	94.90	52.08	16.08
1	1	3	5	3	6.95	7.59	0.0251	0.0811	11.43	63.60	39.84	12.33
3	1	6	0	3	6.39	7.00	0.0172	0.0681	11.98	84.81	58.14	14.68
4	1	1	0	3	6.31	6.93	0.0149	0.0581	14.35	98.68	67.11	17.21
1	1	3	5	4	6.45	7.74	0.0221	0.1294	12.02	65.00	45.25	7.73
3	1	6	0	4	6.82	7.16	0.0193	0.0508	10.79	82.29	51.81	19.69
4	1	5	2.5	4	6.28	6.97	0.0171	0.0691	13.27	86.22	58.48	14.47
1	2	2	5	1	7.03	7.66	0.0179	0.0570	16.11	89.52	55.87	17.54
3	2	2	5	1	6.76	7.16	0.0154	0.0435	14.23	102.16	64.94	22.99
4	2	4	0	1	6.37	6.75	0.0162	0.0455	12.97	96.68	61.73	21.98
1	2	4	0	2	6.65	7.31	0.0184	0.0674	13.47	82.65	54.35	14.84
3	2	1	2.5	2	6.74	7.47	0.0210	0.0758	13.32	74.13	47.62	13.19
4	2	5	5	2	6.76	7.21	0.0176	0.0511	13.43	89.82	56.82	19.57
1	2	3	0	3	6.74	7.62	0.0182	0.0815	13.90	81.12	54.95	12.27
3	2	6	2.5	3	6.64	7.80	0.0219	0.1091	13.30	68.13	45.66	9.17
4	2	1	2.5	3	6.95	7.38	0.0207	0.0495	14.93	83.44	48.31	20.20
1	2	3	0	4	6.63	7.57	0.0256	0.0980	12.98	62.25	39.06	10.20
3	2	6	2.5	4	7.16	7.44	0.0245	0.0448	13.79	76.93	40.82	22.32
4	2	5	5	4	6.80	7.36	0.0219	0.0534	17.78	82.17	45.66	18.73

Appendix 9. Plasma concentrations of urea-nitrogen (PUN, mmol/l), thyroxine (T_4, nmol/l) and triiodothyronine (T_3, nmol/l) of oxen working 0, 2.5 or 5 h/day (TRT) during 3 experimental weeks of 2 weeks each. (Sampling period: 1: before work, 2: week 1, 3:week 2) (Experiment 3)

Animal	Square	Period	Sampling Period	TRT	PUN	T_4	T_3
1	1	3	1	0.0	6.1	46	0.94
1	1	3	3	0.0	4.8	49.5	0.8
1	1	3	2	0.0	4.3	34.6	0.83
3	1	3	1	0.0	6.2	57.3	0.8
3	1	3	3	0.0	2.5	45.2	0.63
3	1	3	2	0.0	3.3	45.6	0.51
4	1	2	2	0.0	1.6	54.1	0.86
4	1	2	3	0.0	4	31	0.49
4	1	2	1	0.0	4	57.4	1.04
6	2	2	2	0.0	1.2	53.5	0.91
6	2	2	3	0.0	4	38.7	0.48
6	2	2	1	0.0	3.7	68.1	0.89
8	2	1	1	0.0	3.8	34.5	0.57
8	2	1	2	0.0	4	52.6	0.48
8	2	1	3	0.0	2.6	55.6	0.57
9	2	3	1	0.0	4	46.5	0.86
9	2	3	3	0.0	3.9	44.7	0.63
9	2	3	2	0.0	5.3	40	0.54
10	3	2	2	0.0	1.6	52.7	0.89
10	3	2	3	0.0	3	39.1	0.71
10	3	2	1	0.0	3	55.9	0.83
11	3	1	1	0.0	2.3	46.5	0.6
11	3	1	2	0.0	2.6	64.5	0.66
11	3	1	3	0.0	1.8	62.4	0.52
12	3	1	1	0.0	3	31.2	0.4
12	3	1	2	0.0	2.9	47.3	0.72
12	3	1	3	0.0	2.4	36.3	0.45
14	4	2	2	0.0	1.8	55.7	0.88
14	4	2	3	0.0	2.6	54.5	0.95
14	4	2	1	0.0	3.4	60.7	1.11
16	4	1	1	0.0	6.8	17.7	0.58
16	4	1	2	0.0	4.1	37.5	0.58
16	4	1	3	0.0	3.7	27.4	0.49
17	4	3	1	0.0	6.1	61.8	0.63
17	4	3	3	0.0	2.7	61.4	0.48
17	4	3	2	0.0	3.5	50.3	0.48

Appendix 9 continued

1	1	1	1	2.5	3.9	25.1	0.81
1	1	1	2	2.5	5.7	37.3	0.72
1	1	1	3	2.5	5.9	31.4	0.8
3	1	1	1	2.5	3.5	33.1	0.55
3	1	1	2	2.5	4.1	35.4	0.54
3	1	1	3	2.5	5.5	31.6	0.45
4	1	3	1	2.5	5.3	34.9	0.61
4	1	3	3	2.5	3.9	37.9	0.61
4	1	3	2	2.5	4.3	34.1	0.52
6	2	3	1	2.5	4.2	42	0.69
6	2	3	3	2.5	4.2	42.1	0.49
6	2	3	2	2.5	3.6	40.9	0.49
8	2	2	2	2.5	1.5	53.7	0.86
8	2	2	3	2.5	4.7	34.9	0.55
8	2	2	1	2.5	3	50.2	0.72
9	2	1	1	2.5	3	36.7	0.63
9	2	1	2	2.5	4.6	39.1	0.65
9	2	1	3	2.5	3.7	33.7	0.57
10	3	3	1	2.5	4.7	39.7	0.84
10	3	3	3	2.5	4.1	28.1	0.36
10	3	3	2	2.5	4.3	33.9	0.63
11	3	2	2	2.5	1.4	74	0.92
11	3	2	3	2.5	3.7	44	0.32
11	3	2	1	2.5	1.6	94.7	0.77
12	3	2	2	2.5	2.1	47	0.72
12	3	2	3	2.5	4.2	31.2	0.45
12	3	2	1	2.5	3.9	55.8	0.69
14	4	3	1	2.5	3.7	35	0.81
14	4	3	3	2.5	4.6	38.7	0.41
14	4	3	2	2.5	3.2	42.2	0.55
16	4	2	2	2.5	2	55.6	0.74
16	4	2	3	2.5	4.8	25	0.55
16	4	2	1	2.5	2.1	56.8	0.65
17	4	1	1	2.5	5.2	39.4	0.52
17	4	1	2	2.5	4.2	39	0.35
17	4	1	3	2.5	5.1	36.1	0.41
1	1	2	2	5.0	5.1	33.1	0.88
1	1	2	3	5.0	8.8	22.6	0.55
1	1	2	1	5.0	5.4	38.5	0.49
3	1	2	2	5.0	4	37.4	0.78
3	1	2	3	5.0	6.2	17.2	0.25

Appendix 9 continued

3	1	2	1	5.0	4.6	56.9	0.55
4	1	1	1	5.0	3.5	33.4	0.71
4	1	1	2	5.0	3.4	31.5	0.57
4	1	1	3	5.0	3.6	26	0.61
6	2	1	1	5.0	3.4	31.1	0.74
6	2	1	2	5.0	4	32.3	0.6
6	2	1	3	5.0	6	23.5	0.18
8	2	3	1	5.0	3.9	44.2	0.72
8	2	3	3	5.0	5.1	34.9	0.38
8	2	3	2	5.0	4.9	40.7	0.54
9	2	2	2	5.0	3.6	41.2	0.61
9	2	2	3	5.0	4.7	28.3	0.35
9	2	2	1	5.0	4.5	56.6	0.71
10	3	1	1	5.0	2.7	33.5	0.8
10	3	1	2	5.0	5.2	32.5	0.63
10	3	1	3	5.0	4.4	25.6	0.52
11	3	3	1	5.0	4.2	78.7	0.69
11	3	3	3	5.0	3	39.9	0.35
11	3	3	2	5.0	3.1	55.1	0.45
12	3	3	1	5.0	5.3	47.8	0.84
12	3	3	3	5.0	4.9	27.6	0.38
12	3	3	2	5.0	5.1	30.4	0.45
14	4	1	1	5.0	3.2	34.2	0.55
14	4	1	2	5.0	4.3	47.3	0.63
14	4	1	3	5.0	6.3	32.6	0.48
16	4	3	1	5.0	4.4	43.3	0.61
16	4	3	3	5.0	9.8	27.9	0.37
16	4	3	2	5.0	6.6	24.3	0.48
17	4	2	2	5.0	2.3	58.8	0.86
17	4	2	3	5.0	6.5	26.5	0.35
17	4	2	1	5.0	1.7	78	0.31

Appendix 10.1. Monitoring of rectal temperatures with thermistors

Rectal temperature is monitored using a 5000Ω thermistor (RS 151-221) unbedded in a stainless steel probe and a Cambpell 21X datalogger. The thermistor is inserted in the probe and held in with a strong epoxy encapsulant. One wire of the thermistor is connected to one 'exitation' channel of the datalogger. The other wire is connected to one 'analog' input of the datalogger. A linearisation resistor (1910 Ω) connects the 'analog' input channel receiving one wire of the thermistor and one 'ground' channel.

Campbell 21X datalogger programme to monitor rectal temperature

Programme 4 (Exite, Delay, Measure) of the Campbell 21X datalogger is used to record temperature with thermistors. Parameters of programme 4 are specified as follows:

```
      P4                Exite, delay, Volt(SE)
01:           4         replicates, 4 thermistors are used here,
02:           5         5000 mV, Slow range
03:           5         Input channel number for first measurement
04:           2         Exitation channel number
05:           10        Delay (units: 0.01 seconds)
06:           1000      mV exitation
07:           7         Input location number for first measurement
08:           x1        Multiplier
09:           x2        Offset

      P92               If time
01:           0000      minutes into a
02:           0001      minute interval
03:           10        set flag 0 (output)

      P71               Average
01:   06:               Replications
02:   07                Location
```

In addition, programmes 71 and 92 ae used to average each minute and to store in final storage, temperatures recorded every 5 seconds

Determination of the reference voltage (Mayet, Y., 1990)

The voltage V_T across the resistor is, by the potential divider principle (see figure below):

$$V_T = V_R \left(\frac{R_T}{R_T + R_L} \right) \qquad (1)$$

Where: V_R = reference voltage
R_L = Fixed linearisation resistor
R_T = resistance of the thermistor

The maximum power P_D, dissipated in the thermistor is

$$P_D = V_T^2 = V_R^2 * \left(\frac{RT}{R_T + R_L} \right)^2 * \left(\frac{1}{R_T} \right) \quad (2)$$

$$= V_R^2 * \frac{R_T}{(R_T + R_L)^2} \quad (3)$$

For the NTC (Negative Temperature coefficient) thermistor, the resistance R_T, at 25 °C, is 5000Ω. Given an RL value of 1910Ω, substituing into equation (3) gives:

$$P_D = V_R^2 * \frac{5000}{(500 + 1910)^2}$$

$$= \quad 0.1047\ V_R^2\ \text{mV} \quad (4)$$

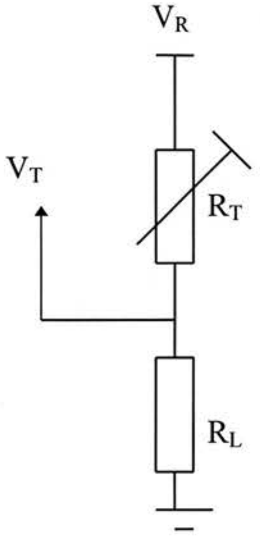
The dissipation constant for the RS 151-221 thermistor is 1 mV. Because of the probe, the dissipation constant has been doubled here. Choosing a maximum self-heating error of 0.05 oC, then the maximum permissible dissipation is 2 mV * 0.05 = 0.1 mV

Since the maximum power dissipated in the thermistor is $0.147\ V_R^2$, then:

$0.147\ V_R^2 = 0.1$
$V_R = 977$ mV

Determination of the multiplier and offset

1. Set the multiplier to 1 and the offset to 0.
2. Measure simultaneously temperature of a water bath with a thermometer and with the rectal probe connected to the datalogger. Intead of Degree units, the datalogger will display microvoltages across the thermistor.
3. Make a series of readings, within the temperature range of interest, and record temperature in degree Celcius from the thermometer and microvoltages displayed by the Campbell 21X datlogger.
4. Estimate the slope and intercept of the regression line of temperature on microvoltage (X axix = mV, Y axis = °C). The multiplier and offset inputs to programme 4 of the Campbell 21X datalogger are the slope and intercept of this regression line, respectively. The value for the multiplier was 0.09639 and the value for the offset was -1.8265.



Thermistor with a series linearisation resistor

Appendix 10.2. Campbell 21X datalogger programme to monitor work output, distance travelled and elaspsed working time:

```
     P3          Pulse
01:  03          Replications
02:  01          Pulse input channel
03:  00          High frequency
04:  0002        Location
05:  1.000       Multiplier
06:  0.000       Offset

     P92         If time is
01:  0000        minutes into a
02:  0001        minute interval
03:  10          set flag 0 (output)

     P72         Totalize
01:  03          Replications
02:  0002        Location
```