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Nutrition of draught oxen in semi-arid west Africa. 1. Energy expenditure by oxen working on soils of different consistencies

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Abstract

The Oxylog, a portable breath-by-breath gas analyser, was used on seven animals to determine standing metabolic rate, energy cost of walking on soils of different consistencies and efficiency of work ploughing and carting. The average standing metabolic rate of animals was 5·63 (s.e. 0·12) W/kg $M^{0.75}$*. The consistency of the soil on which animals worked had a marked effect on their energy cost of walking which was 1·59 (s.e. 0·069) on unploughed soil, 2·15 (s.e. 0·084) on ploughed soil and 1·0 (s.e. 0·10) J/m per kg live weight on laterite tracks. The efficiency of ploughing sandy soils (i.e. ratio of work done to energy used for work) was 0·32 and was not significantly different from the efficiency of carting with different loads. The efficiency of doing work was not influenced by the type of work performed, the draught force exerted or the walking speed.*

Keywords: *draught animals, energy expenditure, work.*

Introduction

Draught animal power was introduced in sub-Saharan Africa during the last 70 years and its use is spreading (Starkey, 1994; Panin and Ellis-Jones, 1994). However, the contribution of draught animals to the power requirements for agriculture is still limited. Agricultural production in this region continues to rely primarily on human power. Statistics in 1987 suggested that proportionately 0·89 of power was provided by humans while draught animals supplied only 0·10 of the farm power input (Food and Agriculture Organization, 1987). There is a need to promote draught animal power in sub-Saharan Africa to fill the gap between the deteriorating level of food production and the increasing demand for food. This is particularly true in semi-arid areas where timeliness in cropping operations is fundamental for successful cropping because of the short growing season in these areas. The low and erratic rainfall regime constrains land preparation and timely planting at the onset of the rainy season. In these situations 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.

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

In the absence of direct measurement of oxygen consumption, the extra energy used to perform

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different activities can be estimated using the factorial method developed by Lawrence and Stibbards (1990). This method integrates, additively, the energy cost of walking, carrying and pulling loads. The energy cost of pulling is fairly constant when expressed in relation to tractive effort and distance. Therefore, this can be accurately predicted if work output is known. Energy cost of walking, which can account for proportionately 0·50 or more of the total energy expended for work (Lawrence and Becker, 1994), is more difficult to predict because it is dependent on ground surface and needs to be determined directly. For instance, Dijkman (1993) found in the sub-humid zone of Nigeria that the energy cost of walking (E_w) in cattle ranged from 8·58 J/m per kg M on ploughed waterlogged rice fields to 1·47 J/m per kg M on unploughed upland soils. The objective of this study was to investigate the energy cost of walking (E_w) and ploughing on sandy soils and of carting in semi-arid areas.

Material and methods

Animals and feeding

This experiment was conducted from October to November 1994 at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Centre at Sadore, Niger. Seven Diali *(Bos indicus)* cattle, average live weight 367 (s.e. 22) kg, aged 5 to 7 years, were used in the study. The animals were given food to about maintenance level on natural pastures supplemented with wheat bran and a mineral mixture (in total about 9 to 10 g/kg $M^{0 \cdot 75}$ per day). The animals had access to water *ad libitum* during the periods when they were not working. Mean ambient temperature and relative humidity were 30·1°C and 0·627, respectively when animals worked in the morning and 36·5°C and 0·242 when work took place in the afternoon.

Experimental methods

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

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

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

The animals used in this experiment were already well trained for work. Further training was necessary to accustom them to carrying the instruments. Animals were trained for 3 weeks to wear the face mask and to carry the backpack containing the ergometer and the Oxylog while performing common farm activities.

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

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

For each activity, measurements were taken when animals had reached a steady rate of oxygen consumption after having worked for at least 5 min. The Oxylog was alternately attached to each animal during each work routine. During the walking sessions, the odometer of the ergometer was wheeled behind the animal to measure distance walked and time spent walking. Animals were allowed to rest for 15 min between bouts of work.

In the second trial the work routine involved the following sequences of activities: standing for 15 min (SMR), walking unloaded around a flat laterite circuit of 1000 m, pulling a two-wheeled cart with pneumatic tyres loaded with 300 kg around the 1000-m circuit, pulling a cart loaded with 600 kg around the 1000-m circuit and finally pulling a cart loaded with 900 kg around the 1000-m circuit. For both carting and ploughing oxen were paired. During the ploughing trials, one ox in each pair walked on unploughed soil and one walked on ploughed soil. However, the position of oxen in the pair was changed during other ploughing sessions so that at the end of the ploughing trial each ox walked both on ploughed and unploughed soils.

Heat production (H) was estimated using the equation: $H = 16{\cdot}18\ \mathrm{O_2} + 5{\cdot}02\ \mathrm{CO_2}$ (Brouwer, 1965) where $\mathrm{O_2}$ is the volume of oxygen consumed and $\mathrm{CO_2}$ is the volume of carbon dioxide produced. Methane and urinary nitrogen were omitted from the equation to calculate heat production proposed by McLean and Tobin (1987) because they would have quantitatively little influence on the estimation of H (see Lawrence *et al.*, 1991). Assuming a value of 0·9 for the respiratory quotient (the ratio of carbon dioxide produced : oxygen consumed), the energy expenditure of animals was estimated from oxygen consumption alone, assuming 20·7 kJ/$\mathrm{O_2}$ consumed (Lawrence and Stibbards, 1990).

The energy cost of walking (E_w J/m walked per kg M) was calculated as E_w = (energy used while walking − energy used while standing still)/(distance walked (m) × M (kg)). The energy cost of doing work was defined as an efficiency factor (E_f) according to Lawrence and Stibbards (1990): E_f = (work done (kJ)/(energy expended when loaded (kJ) − energy expended (kJ) to walk the same distance at the same speed but unloaded).

The information obtained from this experiment was incorporated into a factorial formula (Lawrence and Stibbards, 1990) to predict the extra net energy required for ploughing sandy soils for 1 to 6 h/days:

$$A.F.M + B.F.L + W/C + 9{\cdot}81\ \ H.M/D$$

where: E = extra energy used for work (kJ), F = distance travelled (km), M = live weight (kg), L = load carried (kg), W = work done whilst pulling loads (kJ), H = 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).

The energy cost of ploughing was estimated assuming the average draught force (1047 N for the team or 524 N for each animal) and the average walking speed (0·81 m/s) found in this study. This draught load would be equivalent to 0·16 of the live weight of animals in the pair weighing 300 kg each, 0·12 for animals weighing 400 kg and 0·10 for animals weighing 500 kg. Net energy requirements for maintenance (EM) were estimated as: $EM = 1{\cdot}15(0{\cdot}53[M/1{\cdot}08]^{0{\cdot}67})$ according to Agricultural and Food Research Council (AFRC, 1993). The energy cost for maintenance was increased by proportionally 0·10 to account for the higher metabolic rate after work as compared to non-working days (Lawrence *et al.*, 1989a) and for the higher underlying resting metabolic rate during work as compared to the resting metabolic rate during the same time of the day on non-working days (Lawrence *et al.*, 1989b).

Data analysis

The following statistical model was used to analyse E_w:

$$Y_{ijk} \quad \mu + O_i \quad S_j + \alpha(x_{1ij} \quad x_1) + \beta(x_{:} \qquad\qquad E_{ijk}$$

where: Y = kth observation of E_w for ith animal and jth surface; μ = mean; O_i = effect of animal, ith (i = 1...7); S_j = effect of ground surface, jth, (j = 1: unploughed sandy soil; j = 2: ploughed sandy soil; j = 3: firm laterite track); α = regression coefficient of Y on the speed of walking (x_1); β = regression coefficient of Y on the live weight of the animal (x_2); E_{ijk} = random error.

Table 1 *E gy costs of walking* (E_w) *and walking sp walking on ughed soils, on unploughed soils and late tracks*

Ground surface	No of animals	No.	E_w (J/m per kg) Mean	s.e.	Walking speed (m/s) Mean	s.e.
Unploughed sandy soils			·59	069		
Ploughed sandy soils		20	2·15^b	0·084	0·86^a	0·029
Laterite track		19	1·00^a	0·100	1·26^b	0·033
Significance						

^{a,b} Values in the same cc ımn h erscri are significantly differen

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

Results

Standing metabolic rate

Mean daily energy cost of standing was 5·63 (s.e. 0·12) W/kg $M^{0.75}$.

Energy cost of walking

Ground surface affected E_w and walking speed ($P < 0.01$, Table 1). The energy cost of walking was lowest when the oxen walked on firm laterite tracks. Energy expenditure also was lower when animals walked on unploughed soils as compared with ploughed soils (Table 1). The regression of E_w on M was significant. The heavier the animal, the higher was the energy cost of walking. Each extra kg of M was associated with an increase of 0·013 J/m per kg in the energy cost of walking. Changes in walking speed were not associated with changes in the energy cost of walking. Speed was higher when animals were walking on laterite tracks than when they were walking on sandy field soils (Table 1).

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

Load (kg)	No. of animals	No.	Efficiency of working		Draught force (N)		Walking speed (m/s)	
					Mean	s.e.	Mean	s.e.
300		18	0·32	0·03	310	8·0	1·23	0·02
600		17	0·32	0·03	409	8·1	1·23	0·02
900		16	0·33	0·03	502	8·3	1·19	0·02

Table 3 *Efficiency of doi rk dur by individual oxen*

Animal Number	carting Mean	s.e.	fficiency of ploughing Mean	s.e.
10	0·25	0·14	0·27	0·08
13	0·30	0·09	0·31	0·05
16	0·28	0·03	0·32	0·04
21	0·46	0·05	0·32	0·05
24	0·33	0·05	0·34	0·04

Energy cost of working

The average draught force required to plough sandy soils in this experiment was 1047 (s.e. 43) N. Ploughing was performed using a mouldboard plough at an average depth ranging from 12·9 (s.e. 0·68) to 17·1 (s.e. 0·73) cm. Soil moisture content was 2·2, 2·7, 2·9 and 3·0% at 0 to 5, 5 to 10, 10 to 15 and 15 to 20 cm of depth, respectively. Teams worked at an average speed of 0·81 (s.e. 0·024) m/s. The efficiency of ploughing was 0·31 (s.e. 0·008).

The load during carting, M, draught force and walking speed did not influence working efficiency. The efficiency of doing work during carting was only affected significantly ($P < 0.01$) by individual animals, suggesting large variability between animals (Table 2). The effect of individual oxen on the efficiency of doing work during ploughing was not however significant (Table 3).

Quantification of the extra energy requirements for ploughing

Table 4 shows the net energy required for maintenance and for ploughing sandy soils for each animal in the team, one walking in the furrow and the other walking on the unploughed soil. Depending on M of the animal and the number of hours worked, the daily extra net energy expended for ploughing varied between 0·10 to 0·89 times the energy cost for maintenance.

Discussion

Standing metabolic rate (SMR)

The SMR in this study (5·63 (s.e. 0·12) W/kg $M^{0.75}$) was higher than that recorded by Becker *et al.* (1993) in zebu oxen in Niger (4·75 W/kg $M^{0.75}$) but lower than that calculated from oxygen uptake in resting Bunaji bulls in Nigeria (7·59 W/kg $M^{0.75}$, Dijkman, 1993) and resting crossbred cows in Ethiopia

Table 4 *Live weight, draught force for ploughing as a proportion of live weight (DF/M), daily net energy required for maintenance (EM) and for ploughing (multiple of maintenance) sandy soils for each ox in the pair, one walking on the ploughed soil (A) and the other walking on the unploughed soil (B)*

Live weight (kg)	DF/M	Daily EM (MJ)	'loughing time (h/day											
			1		2				4					
			A	B	A	B	A	B	A	B	A	B	A	B
	0·16	34·75	0·15	0·13	0·29	0·25	0·44	0·38	0·59	0·50	0·74	0·63	0·89	0·75
	0·12	43·12	0·14	0·12	0·28	0·23	0·43	0·35	0·57	0·47	0·70	0·59	0·84	0·70
	0·10	50·99	0·12	0·10	0·24	0·19	0·36	0·30	0·48	0·40	0·60	0·50	0·72	0·59

($9{\cdot}32\ W/kg\ M^{0{\cdot}75}$, Zerbini *et al.*, 1992). Differences in these results may be attributed to differences in breeds used, food intake, climatic conditions, altitude and in the time of day and measuring techniques used in the different experiments. For example in this experiment, SMR was measured before work started whereas SMR values reported by Dijkman (1993) and Zerbini *et al.* (1992) were averages of SMR values before work and between bouts of work (Zerbini *et al.*, 1992) and during recovery periods. Lawrence *et al.* (1989b) found that the rate of energy expenditure of well trained oxen given food at maintenance and standing still between bouts of work was proportionally 0·26 higher than the average rate during the same time of the day when the oxen were in a respiration chamber. The high value of $9{\cdot}32\ W/kg\ M^{0{\cdot}75}$ reported by Zerbini *et al.* (1992) may be related to the *Bos tauras* × *Bos indicus* crossbred dairy cows they used. Those animals may have had a higher metabolic rate than the *Bos indicus* breeds used in this and the other experiments (Dijkman, 1993; Becker *et al.*, 1993). In Ethiopia, crossbred oxen were found to require more energy per unit of body weight for maintenance and work output than local oxen (Astatke, 1983). It is important to note first that the SMR reported in these studies is related to total M and not to empty body mass. Secondly, the energy expenditure measured while the animal was standing still includes heat increment.

Energy cost of walking

The significant effect of ground surface (unploughed and ploughed sandy soils and laterite tracks) on the energy cost of walking agrees with results reported by Dijkman (1993). The E_w of 1·59 J/m per kg M on unploughed sandy soils found in this experiment is close to the E_w of 1·47 J/m per kg M on unploughed upland and the E_w of 1·76 J/m per kg M on unploughed dry valley bottom soils found by Dijkman (1993) in Nigeria. As might be expected, E_w on ploughed land was lower on the sandy soils in the present study (2·15 J/m per kg M) than seen on ploughed land on the heavier soils with a higher clay content in valley bottoms in Nigeria, (3·76 to 8·58 J/m per kg M; Dijkman, 1993).

The energy costs of walking on firm surfaces (unploughed land and laterite tracks) found in this study were similar to other measurements made in the field. Becker *et al.* (1993) reported an E_w of 1·34 J/m per kg in zebu cattle in Niger, and Clar (1991) found an E_w of 1·00 J/m per kg also for zebu cattle in Niger that was similar to the E_w measured on laterite tracks in this study. Field values recorded on the firm surfaces were usually lower than values determined on treadmills such as: 2·6 J/m per kg (AFRC, 1993), 1·9 J/m per kg (Brody, 1945) and 2·1 J/m per kg (Lawrence and Stibbards, 1990). Discrepancies between laboratory and field values of E_w can be explained by the artificial conditions of the former. When oxen walk in the field they travel at their own speed and are likely to be more at ease than on a treadmill in a laboratory, where they have to walk at a set speed on a moving treadmill surface. This illustrates the value of conducting field measurements to establish the true energy requirements of working animals.

In this experiment the energy cost of walking was independent of the walking speed. The energy cost of walking increases as speed decreases if the rest-maintenance component of the cost is included (Brody, 1945). However, if the maintenance cost is excluded from the total energy cost, as was done here in the calculation of the E_w, then the energy cost of walking is independent of speed. Lawrence and Stibbards (1990) also found that when oxen were walking at a comfortable speed, i.e. either forced to walk very slowly or very fast, but at a speed they might choose naturally, then the energy cost of walking was no longer influenced by speed.

Energy cost of doing work

In this experiment the efficiency of doing work was not affected either by the type of work performed (ploughing *v.* carting with varying loads) or the draught force exerted. The efficiency of ploughing

(0·31) was consistent with average efficiencies of pulling loads reported by Lawrence and Stibbards (1990). These results are also in agreement with Dijkman (1993) who found an average efficiency of 0·30 to 0·31 for oxen ploughing upland and valley bottom soils in Nigeria. Efficiency of doing work in the present study was unaffected by walking speed. This again agrees with the observations of Lawrence and Stibbards (1990).

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

Lawrence (1985) estimated the energy expenditure of cattle working in land preparation for 5·5 h/day to be 0·42 to 0·67 times maintenance requirements Pearson (1989) reported estimated extra daily energy requirements of 0·74 to 0·78 times maintenance energy requirements for cattle pulling carts for 5 h/day. Over a shorter working day (3 h) Mahardika *et al.* (1994) estimated the extra energy expenditure of water buffaloes working at draught forces equivalent to proportionally 0·10 and 0·15 of M to be 0·42 and 0·48 times maintenance energy requirements, respectively. Using the values for E_w and the efficiency of doing work obtained in this study to estimate the extra net energy used for work according to the method of Lawrence and Stibbards (1990) gave values for the extra energy for work ranging from 0·10 to 0·89 times daily maintenance energy requirements, depending on the number of hours worked and the size of the animals used. The estimated energy expenditure during 5 to 6 h of ploughing sandy soils varied between 0·50 for oxen weighing 500 kg to 0·89 × maintenance for oxen weighing 300 kg. The energy expenditure during work of the 500-kg ox was comparable to that seen in the other studies (Lawrence, 1985; Pearson, 1989; Mahardika *et al.*, 1994), but energy expenditure during work by the 300-kg ox was higher than that generally found, suggesting that the larger animal (500 kg) is the better one to use for ploughing in the semi-arid areas.

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

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