Nutrient Requirements of Exercising Swamp Buffalo, *Bubalus bubalis*. II. Details of Work Energy of Cows and Its Relation to Heart Rate[a]

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ABSTRACT : Four young swamp buffalo cows of similar age ranging in body weight (W) between 280 to 380 kg and trained for doing physical exercise were used in two consecutive experiments, each using a latin square design, to determine energy expenditure for draught. The experiments consisted of field trials using 4 levels of work load, i.e. no work as control and loads amounting 450 to 500 Newton (N) continuous traction for respectively 1, 2 and 3 h daily for 14 consecutive days for experiment 1, and no work, traction loads equaling 5, 10 and 15% of W for 3 h daily for 14 days for experiment 2. Heart rate during rest and exercise was monitored using PE-3000 HR monitor. Cows were fed only king grass (*Penisetum purpuroides*) *ad libitum* and were subjected to balance trials. Body composition was estimated *in vivo* by the body density method and daily energy expenditure (EE) was calculated from ME minus RE. RE was calculated from the changes in body-protein and -fat measured before and immediately after the 14 d experimental period assuming an energy equivalent of 39.32 MJ/kg fat and 20.07 MJ/kg protein. $E_{exercise}$ (EE_{work} - $EE_{resting}$), which was the energy spent for doing the traction during 1, 2 and 3 h was 7.13, 15.45 and 19.90 MJ, respectively. EE_{work} for the 1 h treatment group was 39.75 MJ/d equivalent to 1.30 times $EE_{resting}$. The values for the 2 and 3 h treatment groups were 1.75 and 1.86 times resting energy requirement, respectively. Absolute efficiency of work in all exercise trials of experiment 2 was around 27.28%. The increases of daily $E_{exercise}$ values were correlated to elevation of heart rate (HR) according to the equation $E_{exercise}=(0.270\ HR^{0.363} - 1)$ MJ, while draught force related to heart rate according to the equation DF (N)=6.66 HR - 361.62. Blood glucose and triglyceride levels were gradually elevated with time during the course of exercise. Mean values of blood glucose were 91.7, 115.0 and 116.2 mg/dl for cows after 1, 2 and 3 h pulling loads at 15% W respectively as compared to 88.2 mg/dl prior to work. In the same order and treatment, mean blood triglyceride concentrations were 13.5, 13.3 and 14.8 mg/dl, and 11.5 mg/dl for control. For blood lactate, the values were 1.68, 1.63 and 1.66 mM, and 0.80 mM for control. Glucose was used as the major source of energy during the initial phase of exercise, but for prolonged work, fat will replace carbohydrate as the main substrate. Accumulation of lactate persisted for some time at the end of the exercise trials. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 7 : 1003-1009)*

Key Words : Swamp Buffalo, Heart Rate, Glucose, Triglyceride, Exercise, Energy Expenditure, Draught Work

INTRODUCTION

The swamp buffalo is an excellent draught animal that is well adapted to intensive small holder farming, especially female buffalo can be worked to a greater extent than female cattle without effects on reproduction and milk yield (Falvey, 1985). To meet nutrient requirements, it is obvious that extra energy is needed for draught and for this requirement, one needs to know how much energy will be needed for work and the heat increment associated with work which could then be translated into quantities of food (Lawrence, 1985). Mahardika et al. (2000) reported results of a study to measure the energy and protein balance of working swamp buffalo cows in the field, involving the use of data on body composition by the *in vivo* body density method (Kleiber, 1961) to determine energy and protein requirements. The present study is to document the energy for work and its components measured according to the factorial method (Lawrence, 1985; Lawrence and Stibbards, 1990; Bakrie and Masum, 1993). In addition, blood metabolites and heart rate (HR) of the exercising cows were monitored. HR, as a practical index is needed for predictive purposes to estimate extra energy for draught. The inference of energy expenditure from HR monitoring is considered suitable for field application (Ceesey et al., 1989; Rometsch and Becker, 1993); thus attempts were also made to relate increase of daily energy expenditure with HR.

MATERIALS AND METHODS

The study consisted of 2 field experiments. Detailed descriptions of experimental design and

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protocol, body composition and measurement of daily EE, energy for exercise ($E_{exercise}$) in the field and statistical analysis have been given in an earlier publication (Mahardika et al., 2000), but will be briefly described below.

Experiment 1

Four non-pregnant, non-lactating swamp buffalo cows weighing 280 to 380 kg which had been trained to do daily exercise were used for the study. The training program was to pull loads on a sledge continuously for 3 h during a period of 2 to 3 months. Except when doing field exercise, the buffaloes were placed continuously in individual pens with facilities for balance trials. The animals received king grass (*Penisetum purpuroides*) aged 45 to 55 days as the sole feed given *ad libitum*, while water was offered twice a day at noon and in the evening. Experiment 1 was designed in a 4×4 latin square arrangement involving 4 buffalo cows and 4 treatments of pulling loads of 450 to 500 N daily for zero (treatment A), 1 (treatment B), 2 (treatment C) and 3 h (treatment D) continuously for 14 consecutive days, respectively. The traction equipment was a sledge loaded with the driver and weights and a spring traction scale to measure draught force, a distance measuring device and a stopwatch to quantitate the treatment load. The animals wore a single shoulder yoke during draught; the angle (α) between traction force and horizontal level was carefully recorded. Readings of draught force F (traction scale readings in kg multiplied by g=9.81 m/sec^2 to transform to Newton units) were recorded by visual observation at 2 minute intervals during 30 min at the start (from minute 0 to 30 of the traction period), during 30 min in the middle (from minute 75 to 105) and during 30 min before termination of the exercise (from minute 150 to 180).

Experiment 2

After termination of experiment 1, the same animals were subsequently used in a repeat experiment with the same details as for experiment 1 except that the exercise treatments were pulling loads amounting to 0% (control, treatment A), 5% (treatment B), 10% (treatment C) and 15% (treatment D) of bodyweight (W) continuously for 3 h. Live weight W of the buffaloes ranged from 280 to 380 kg and draught force F was calculated from the traction scale readings. Just before the start, and immediately after the first, 2nd and 3rd h of exercise, blood samples were taken from 2 cows of each treatment group via jugular vein for determination of glucose, lactate and triglyceride concentrations. Analyses of these blood plasma metabolites were carried out according to common clinical laboratory methods. The $E_{exercise}$ components were calculated according to the factorial method of Lawrence ($E_{exercise}$=aWD + bLD + E_{pull}/c) but using modified values of coefficients a, b and c for buffalo found by Mahardika et al. (2000), i.e. a=2.56 J/kgW.m, b=5.2 J/kgL.m and c=0.29 (29%). $E_{exercise}$=energy used for the work exercise (kJ), W=live weight (kg), D=distance traveled (km), L=load carried (kg)=F sinα; F=measured draught force and α is traction angle, E_{pull}=work done in pulling a load (kJ)=F cosα (N)×D (km).

In vivo measurement of body composition and retained energy (RE)

Using the body density method involving measurement of the animal's volume, the buffalo cow was carefully lowered and immersed in a concrete basin fully filled with water measuring 2 m (length)× 1.0 m (width)×1.0 m (depth) constructed in the ground with a sloping entrance. The overflow of water was totally collected in a special constructed container beside the basin and measured to estimate the animal's body volume. Body protein was calculated using an equation relating to the ratio of meat to bone (R_d), which are the components of lean minus blood, and body weight (W in kg), according to the equation: R_d=2.861+0.0109W (r^2=0.99; SD=0.27) derived from swamp buffalo data. Body protein was then calculated by multiplying protein percentage of swamp buffalo meat to quantity of meat. RE was calculated from the changes in body-protein and -fat measured before and immediately after the 14 d experimental period assuming an energy equivalent of 39.32 MJ/kg fat and 20.07 MJ/kg protein.

Measurement of daily energy expenditure (EE) and calculations of work efficiencies

Daily EE was calculated from ME (from balance trial) minus RE. In addition to using the Lawrence equation, $E_{exercise}$ was also calculated as the difference between daily EE while the cow was performing work (EE_{work}) and daily EE while resting ($EE_{resting}$).

The following efficiency categories of work were calculated (Lawrence, 1985): Total work efficiency (%)=[E_{mech}/EE_{work}]×100%; Net (work) efficiency (%)=[E_{mech}/$E_{exercise}$]×100%; Absolute (work) efficiency (%)=[E_{mech}/($E_{exercise}$ - $E_{walking}$)]×100%.

Heart rate monitoring

The PE-3000 HR monitor for humans consists of a chest belt holding a pulse sensor which at the same time transmits HR values to a "wrist-watch" receiver. HR was continuously transmitted as electro-cardiographic (ECG) signals after computerized noise filtering. Signals could be stored as 5, 15 or 60s averages. The storage capacity for the 60s mode used in the present study is up to 33 h. The distance

Table 1. Mean ± SE values of speed, distance traveled, draught force, heart rate, exercise energy components, and efficiencies of swamp buffalo cows undertaking different work loads

Variables		Exercise treatment*				SEM**
		A	B	C	D	
Draught force (N)	Exp. 1	0^a	452 ± 3.67^b	485 ± 1.85^b	472 ± 1.49^b	2.578
	Exp. 2	0^a	152.75 ± 2.63^b	345.00 ± 2.90^c	470.20 ± 2.41^d	1.606
HR*** of Exp. 2 (walking)		58.5 ± 1.29	72.0 ± 1.83	108.0 ± 1.56	123.0 ± 2.53	1.995
Speed (m/s)	Exp. 1	0^a	0.79 ± 0.014^b	0.77 ± 0.017^b	0.67 ± 0.003^c	0.014
	Exp. 2	0^a	1.06 ± 0.021^b	0.96 ± 0.028^c	0.84 ± 0.007^d	0.021
Distance (km achieved)	Exp. 1	0^a	2.81 ± 0.050^b	5.57 ± 0.128^c	7.23 ± 0.019^d	0.096
(km/3 h)	Exp. 2	0^a	11.42 ± 0.184^b	10.35 ± 0.297^c	9.07 ± 0.099^d	0.221
En. walking (MJ/distance)	Exp. 1	0^a	1.78 ± 0.104^b	4.06 ± 0.135^c	5.50 ± 0.272^d	0.999
(MJ/3 h)	Exp. 2	0^a	8.84 ± 0.50^b	9.19 ± 0.254^c	8.40 ± 0.085^d	0.418
En. carry load (MJ/ex.)	Exp. 1	0^a	1.99 ± 0.072^b	4.24 ± 0.170^c	5.37 ± 0.271^d	0.266
(MJ/3 h)	Exp. 2	0^a	0.37 ± 0.028^b	0.65 ± 0.035^c	0.83 ± 0.007^d	0.029
En. pull. load (MJ/ex.)	Exp. 1	0^a	3.36 ± 0.087^b	7.15 ± 0.132^c	9.04 ± 0.074^d	0.144
(MJ/3 h)	Exp. 2	0^a	6.09 ± 0.276^b	10.30 ± 0.615^c	12.96 ± 0.233^d	0.573
En. exercise (MJ/exerc.)	Exp. 1	0^a	7.13 ± 0.134^b	15.45 ± 0.106^c	19.90 ± 0.332^d	0.183
(MJ/3 h)	Exp. 2	0^a	15.30 ± 0.757^b	20.13 ± 0.891^c	22.18 ± 0.290^d	0.199
Mechanical en. (MJ/3 h)	Exp. 2	0^a	1.77 ± 0.056^b	2.99 ± 0.123^c	3.76 ± 0.048^d	0.166
+Total work eff. (%)	Exp. 1	0^a	2.53 ± 0.153^b	4.21 ± 0.064^c	4.781 ± 0.071^d	0.123
	Exp. 2	0^a	3.86 ± 0.073^b	5.54 ± 0.175^c	6.59 ± 0.072^d	0.214
++Net efficiency (%)	Exp. 1	0^a	13.25 ± 0.459^b	13.42 ± 0.240^b	13.21 ± 0.260^b	0.420
	Exp. 2	0^a	11.55 ± 0.191^b	14.83 ± 0.178^c	16.94 ± 0.079^d	0.319
+++Absolute eff. (%)	Exp. 1	0^a	18.60 ± 0.793^b	18.63 ± 0.154^b	18.081 ± 0164^b	0.710
	Exp. 2	0^a	27.32 ± 0.070^b	27.28 ± 0.039^c	27.27 ± 0.026^c	0.0845
Daily EE (MJ/d)	Exp. 1	30.383 ± 2.351^a	39.715 ± 1.116^b	53.536 ± 1.106^c	60.352 ± 1.234^d	1.633
	Exp. 2	30.65 ± 2.05^a	45.76 ± 3.32^b	53.88 ± 1.28^c	57.02 ± 0.97^d	1.152

* Treatments A, B, C and D for Experiment 1 were traction 450 to 500 Newton (N) for 0, 1, 2 and 3 h, respectively; for Experiment 2 were continuous traction for 3 h at 0, 5, 10 and 15% of bodyweight (W), respectively.

** SEM=Standard error of the treatment means.

*** HR of Experiment 2: Mean ± SE of heart rate during the respective work loads.

Means in a row differing superscripts (a, b, c, d) differ significantly at $p<0.05$.

between the "wrist-watch" receiver and the transmitter should not exceed 1 m, and for use with large animals the receiver can be fastened to the belt (girth strap) at about the height of the animal's spine. Due to its superior features, PE-3000 was used in the present study.

For use on buffalo however, one should consider the relatively high impedance of the thick buffalo hide. Therefore we felt the need to use an operational amplifier (op-amp) inserted between electrode and the pulse sensor to improve sensitivity of the system, while skin contact has to be secured by using self-made copper electrodes with a rough contact surface augmented by electrode gel. The op-amp possesses a noise filter for better performance of the system. Electrodes and op-amp were fixed in a modified girth strap that fits the buffalo.

Statistical analysis

The data obtained were subjected to analysis of variance and if significant differences were obtained between treatments, the data were further analyzed by the Duncan Multiple Range Test (Steel and Torrie, 1986). Calculation of equations to relate different measured variables employed models using Lotus 123 release 5 program.

RESULTS AND DISCUSSION

Results on exercise performance of working buffalo cows from experiments 1 and 2 are presented in table 1. The walking speed of buffalo cow pulling a load of 5% W was 1.06 m/s, while increasing the loads up to 15% W resulted in reduction of walking speed to 0.84 m/s. The distance traveled during the 3 h exercise pulling 5% W load was 11.42 km. Reduction in speed due to heavier loads would reduce the walking distance traveled, e.g. to 9.07 km with the 15% W load. Smith (1988) reported a walking speed of 1 m/s during the first 10 minutes of 400 N traction, the speed decreasing with longer exercise duration. Studies by Borton (1987) revealed that

Table 2. Comparison of results using PE-3000 HR monitoring system with readings obtained by audio amplified stethoscopic observation (Mean±SD)

Exercise level	X[1] PE-3000 system	Y[2] stethoscopic	Regression equation
Slow walk	57.2±1.79	56.0±1.23	
Walk, slightly faster	67.2±1.64	66.8±1.48	Y=-0.60+0.999X
" + pulling ~5%[3] W load	77.4±3.05	77.2±4.27	r^2=0.995
" + pulling ~8%[3] W load	94.0±1.87	92.2±1.92	SE of X coefficient 0.015
" + pulling ~10%[3] W load	106.0±1.87	108.0±2.55	SE of Y estimate 1.82

[1] X=PE-3000 system heart rate reading (beats/min).
[2] Y=Audio amplified stethoscopic reading of heart rate (beats/min).
[3] W=Body mass (kg).

exercising buffalo pulling loads amounting 6 to 10% W would display speeds averaging 0.61 m/s. All these speeds, including our results, are greater than those reported for cattle with comparable traction loads, indicating better capability of buffalo as compared to cattle for tilling larger areas of soil.

On the different energy categories of work (table 1), the present results show that energy for walking for treatments 5, 10 and 15% W loads were 8.84, 9.19 and 8.40 MJ, respectively. The energies needed to carry and to pull loads for the 5% W treatment were 0.37 and 6.09 MJ, respectively. Increasing loads would elevate energy needs for carrying and pulling. Reduction in energy expenditure for walking due to increasing loads was attributed to reduction of walking speed, causing shorter distance traveled by the animal, while the increase in energy needs for treatments 10 and 15% W loads were due to the heavier loads. Lawrence and Dijkman (1991) reported that swamp buffalo walking with a speed of 0.9 to 1.0 m/s required a walking energy amounting 1.5 to 3.3 J/m.kgW. Lawrence (1985) also reported that the energy required for buffalo to move 1 m carrying 1 kg load is 4.2 J; thus an increase of pulling force would increase energy expended for work.

Total energy for work increases parallel with work load. Earlier results show that resting energy was 0.42 $Wkg^{0.75}$ MJ/day (Mahardika et al., 2000) and daily EE would be resting energy plus energy required for work. Calculations demonstrate that daily EE of buffalo receiving treatment A, B, C and D in experiment 2 were 30.65, 45.76, 53.88 and 57.02 MJ, respectively, thus ranging from 1.49 to 1.86 times resting daily EE. Bamualim and Katiarso (1985) found daily EE in buffalo working 2 to 4 h/d to be 34.02 to 58.99 MJ, while Leng (1985) found for light exercising buffalo (walking for 6 h without load) 1.5 times resting daily EE; the value increased up to twice that cost for heavy working animals (6 h/d). For comparison, Lawrence (1985) found 1.67 times resting EE in working cattle. The energy expended by the buffalo cow undertaking 450 to 500 N traction (experiment 1) during 1 h was 7.13 MJ and those working for 2 and 3 h were 15.45 and 19.90 MJ, respectively. The values show that those working for 2 h expended 2.17 times the energy required for exercise of 1 h, while those working for 3 h required 2.79 times that working for 1 h. In addition, the increment of energy requirement from 1 to 2 h was higher than the increment from 2 to 3 h exercise. This phenomenon was attributed to the slower speed shown by the animals working longer. The mean speeds of buffalo doing traction work during 1, 2 and 3 h were respectively 0.79, 0.77 and 0.67 m/s. The results were in line with the results reported by Teleni and Hogan (1989) for cattle and buffalo pulling loads 10 to 14% W, having walking speeds of 0.6 to 1.1 m/s during 3 h work.

The mechanical energy which was displayed by buffalo pulling a load of 5% W during 3 h was 1.77 MJ, while those pulling loads of 10 and 15% W for 3h were 2.99 and 3.76 MJ, respectively. Increase of work load resulted in increase of mechanical work. Total and net efficiencies would also increase with increasing work loads, but absolute efficiency decreased. The fact that increase in work duration decreased absolute efficiency was caused by a larger proportion of energy that were dissipated as heat with increasing work load. Decrease in efficiency for the animals undertaking heavier work load indicated that a load of 15% W is too heavy for the buffalo cow. Goe (1983) stated that buffalo performing traction of 10 to 14% W would show walking speeds of 2.5 to 4 km/h, while Teleni and Hogan (1989) reported for cattle and buffalo undertaking traction of 11% W, the speed would be 2.5 km/h during 3 h continuous work.

HR measurements have been carried out with walking animals. Bayer (1966), Webster (1967), Richards and Lawrence (1984) and Physick-Sheard et al. (1982) used an ECG to record voltage variations on the skin during movement, which they interpreted as cardiac action potentials mixed with muscle action potentials and random noise. The random noise was caused by changes in the resistance between skin and

Table 3. Mean ± SD of blood plasma glucose, triglyceride and lactate levels of working swamp buffalo cows

Blood metabolite concentration	Work treatment				SEM
	No work	Draught 5% W	Draught 10% W	Draught 15% W	
Glucose (mg/dl)					
Prior to work	85.8 ±4.19[a]	82.3 ±4.11[a]	79.3 ±3.09[a]	88.2 ±6.23[a]	2.64
1 h after start of work	81.0 ±2.94[a]	70.2 ±3.86[b]	67.5 ±2.65[b]	91.7 ±4.99[c]	2.14
2 h after start of work	77.8 ±2.50[a]	80.0 ±7.07[a]	85.5 ±5.57[a]	115.0 ±5.94[b]	3.18
3 h after start of work	87.3 ±7.80[a]	95.2 ±3.30[a]	90.3 ±3.86[a]	116.2 ±5.79[b]	3.17
Triglyceride (mg/dl)					
Prior to work	11.2 ±2.63[a]	13.0 ±2.16[a]	12.0 ±1.63[a]	11.5 ±2.08a	1.24
1 h after start of work	13.0 ±2.94[a]	23.5 ±3.42[b]	18.0 ±4.24[ab]	13.5 ±4.04[a]	2.13
2 h after start of work	9.2 ±2.63[a]	24.2 ±3.09[b]	18.2 ±1.71[c]	13.3 ±3.09[a]	1.55
3 h after start of work	11.7 ±1.71[a]	23.5 ±3.32[b]	15.0 ±1.41[c]	14.83±2.50[ac]	1.36
Lactate (mM)					
Prior to work	0.75±0.04[a]	0.80±0.03[a]	0.71±0.04[a]	0.80±0.03[a]	0.02
1 h after start of work	0.85±0.04[a]	0.66±0.05[b]	1.43±0.09[c]	1.68±0.05[d]	0.04
2 h after start of work	0.71±0.09[a]	1.00±0.11[b]	1.45±0.08[c]	1.63±0.09[d]	0.05
3 h after start of work	0.85±0.05[a]	1.20±0.06[b]	1.56±0.09[c]	1.66±0.07[c]	0.04

Means in a row differing superscripts (a, b, c, d) differ significantly at $p<0.05$.
SEM=Standard error of the treatment mean.

electrode or by vibrations (Richard and Lawrence, 1984) or by slipping of the electrodes (Webster, 1967) which can blur the ECG signal. Rometsch and Becker (1993) described a pulse sensor which enabled detailed recordings to be made of the response of the heart to physical parameters without interference while the animal is standing or walking. Ceesey et al. (1989) conducted a calibration test with PE-3000 on humans in which the HR monitor was compared with a multi-lead reference ECG at HR up to 164 beats/min of exercising individuals and concluded the monitor is reliable.

A calibration test was performed in which the modified PE-3000 HR monitoring system for swamp buffalo was compared with the heart beats monitored with the help of a stethoscope (audio amplified by connection to an electret condenser microphone and small battery operated portable amplifier) over several minutes on an individual doing a multi level exercise test. The results are presented in table 2. Linear regression produced r^2=0.995 with a slope of 0.999 and SE of coefficient 0.015. The linear equation is $Y=-0.60+0.99X$, where X is PE-3000 and Y is stethoscopic readings, respectively. The results demonstrate the satisfactory performance of the system.

Resting swamp buffalo cows have a heart rate of 35 to 42 beats/min (figure 1). Richards and Lawrence (1984) found heart rate of buffalo is lower than that of cattle which could be attributed to differences in anatomy and the cardiovascular system between the two animal species. Figure 1 shows the relationship between $E_{exercise}$ and heart rate described by the following equation which includes resting values: $E_{exercise}=0.270\ HR^{0.363} - 1$ (r^2=0.94; SD=0.20), where $E_{exercise}$ is expressed in kJ and HR is heart rate in beats/min.

Similarly, as shown in table 1 there is also a strong relationship between draught force and heart rate. The linear regression of heart rate on draught force and vice versa, are given as follows: HR=0.15 DF+55.33 (r^2=0.97; SD=0.006); DF=6.66 HR - 361.62 (r^2=0.97; SD=0.28), where DF is draught force in N.

The results are in agreement with, and show an even closer relationship between HR and DF than Rometsch and Becker (1993) who found a reasonable correlation between those variables of r=0.80.

Data on blood plasma metabolites are presented in table 3. The data show clearly the trend of change of levels due to different length of work and work loads. Plasma glucose of cows undertaking 15% W traction loads increased during the course of work in contrast to those undertaking 5 and 10% W loads where the elevation of plasma glucose occurred by the 2nd h onward. Although not statistically analyzed due to limitations imposed by the experimental design, blood glucose and triglyceride levels were gradually elevated with time during the course of undertaking exercise. The elevations of plasma glucose were likely due to glucose from mobilization of glycogen reserves, gluconeogenesis from glycerol and amino acids, and perhaps prevention of glucose entering peripheral cells because of lowered insulin secretion. In addition, prolonged exercise would use fat as an energy source hindering glucose utilization (Power and Howley, 1991). Prolonged exercise would stimulate epinephrine, thyroxin and glucagon release, but lowering insulin secretion, and all these factors would activate lipase resulting in lipolysis and, consequently, triglycerides

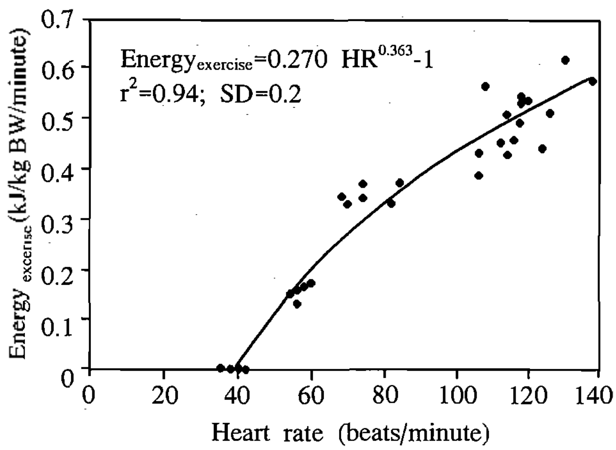

Figure 1. Relationship between $E_{exercise}$ (kJ) and heart rate (HR, beats/minute) in exercising swamp buffalo cows

levels were elevated.

There is much evidence to suggest that at the onset of exercise the ATP-creatine phosphate system is the first active bio-energetic pathway followed by glycolysis, but subsequently, the body's ATP requirement is met via aerobic metabolism with actually considerable overlap among the metabolic systems. Aerobic oxidation of glucose and fat involves the interaction of the Krebs cycle and electron transport chain for the aerobic production of ATP. Powers et al. (1980) stated that during prolonged exercise there is a gradual shift from carbohydrate metabolism toward an increasing reliance on fat as an energy source.

Glycolysis is the production of ATP by anaerobic breakdown of glucose to form 2 molecules of pyruvic acid or lactic acid. Plasma lactate concentration increased during exercise, especially in cows on the 10 and 15% W loads. Lactate accumulation would be the result of increased production combined with a decrease in the rate of removal due to inadequate supply of oxygen during heavy exercise (Powers and Howley, 1990).

In conclusion, the results of the present study with swamp buffalo cows indicate that heavier traction loads would elevate energies required for carrying and pulling loads causing reduction in walking speed, walking distance traveled and ultimately also in the energy required for walking. Mechanical and total energy expended for work would also increase which consequently increase total and net work efficiencies, but lowered absolute efficiency which led to the conclusion that traction at 15% W is too heavy for the swamp buffalo cow. The data on blood metabolites consolidate our conventional wisdom as they relate to metabolic systems of energy generation for long-term exercise. It was also found that heart rate would be an adequate index of energy for draught.

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