EFFECT OF EXERCISE ON MILK YIELD, MILK COMPOSITION AND BLOOD METABOLITE CONCENTRATIONS IN HEREFORD × FRIESIAN CATTLE

R. W. Matthewman[1], J. Merrit, J. D. Oldham[2] and G. W. Horgan[3]

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

Summary

Three experiments were carried out in which lactating Hereford × Friesian cattle walked up to ten kilometres a day for three periods of five days with two non-walking days between each walking period and in which the animals were fed different diets. Measurements were made of milk yield, milk constituent yields and concentrations and blood metabolite concentrations. Exercise caused significant reductions in milk yield and in the yields of lactose and milk protein. Milk fat yield was not reduced when animals were exercised. During exercise the concentrations of β-OH butyrate and free fatty acids increased, whereas the concentrations of glucose, magnesium and inorganic phosphorus decreased. Diet influenced the effect of exercise on some blood metabolite concentrations.
(**Key Words**: Cattle, Milk, Milk Composition, Blood Metabolites, Draught, Exercise and Work)

Introduction

Draught animals provide the tractive effort for cultivation and transport in many parts of the world. Female cattle form a large part of draught animal populations and in countries such as Bangladesh this proportion is increasing (Ahmed, 1978). The effects of the energy demands for work on lactational performance are not well understood. Previous published literature (Krantforst, 1947; Rajapurohit, 1979; Munzinger, 1982; Kibria, 1982; Goe, 1983; Barton, 1987) offered conflicting evidence and often only speculative viewpoints about the effects of work on milk yield and milk composition and the consequent implications for nutrition.

It has been suggested that the increased nutrient demand of work for lactating and pregnant cows may cause imbalance in the supply of glucose and its precursors (Lindsay, 1959; Leng, 1980).

Studies with sheep (Bird, Chandler and Bell, 1981; Pethick, 1984) indicate that exercise increases the use of nutrients which are important for the support of lactation. Exercise increases glucose and free fatty acid uptake by the hind limb, 3-4 fold, with a smaller proportionate increase in the uptake of acetate. Jarrett, Filsell and Ballard (1976) emphasised the role of free fatty acids as a primary metabolic fuel during exercise, but Pethick, Harman and Chong (1987) placed a much greater emphasis on glucose utilization. Glucose and free fatty acids are likely to be in high demand for support of work and milk production, but perhaps especially glucose, because of its role in lactose production (Kuhn, 1983). Previous work with lactating cattle (Rizwan-ul-Muqtadir, Gill, Ahmad and Ahmad, 1975; Barton, 1987) has not clearly indicated the manner in which exercise effects the proportions of milk constituents and the use of nutrients for lactation.

The purpose of this work was to measure the effect of exercise on the secretion of milk constituents and on the use of nutrients for lactation in exercising cattle.

Materials and Methods

Three experiments were conducted, each using Hereford × Friesian suckler cows from the

[1]Address reprint requests to Dr. R. W. Matthewman, Centre for Tropical Veterinary Medicine, Roslin, Midlothian, EH25 9RG, UK.

[2]Department of Genetics and Behavioural Sciences, Scottish Agricultural College, Bush Estate, Penicuik, Midlothian, EH26 OQE, UK.

[3]Scottish Agricultural Statistics Service, James Clerk Maxwell Building, Kings Buildings, Mayfield Road, Edinburgh EH9 3JZ, UK.

Received May 18, 1993
Accepted August 25, 1993

Edinburgh School of Agriculture's autumn-calving suckler herd. The animals were all second parity or greater and calved in August to October in the year preceding experimental studies, which were conducted in May to July. The cows were in their sixth or subsequent month of lactation at the beginning of each experiment.

Before the experiments started the calves were gradually weaned while the cows were introduced to the new diets and to machine milking into buckets. This procedure took about 7 days, when the calves were finally removed. Milking was carried out twice per day at 7 a.m. and 6 p.m. daily. Samples for milk constituent analysis were taken at individual milkings on Mondays, Wednesdays, Fridays and Sundays and analysed for fat, protein and lactose by infra-red milk analyser. When housed, the animals were tied by the neck in concrete standings with rubber mats. When walking, they followed a path which for each circuit covered 880 metres in distance and a change in elevation of 40 metres.

The cows were weighed twice a week.

Experiment 1

The objective of this experiment was to measure the effect of a fixed amount of exercise on milk yield, milk composition and body weight change. Twelve cows were used which were offered fixed amounts of a complete pelletted feed (high roughage diet HR), rationed to individual cows to supply sufficient metabolisable energy to meet ME needs (according to ARC, 1980) for milk production and maintenance of body weight measured in the week immediately preceding the formal experiment. A daily allowance of 7 MJ ME was allowed for pregnancy. Composition of the diet is shown in table 1. Feeding was twice per day at milking times.

The exercise treatment consisted of 10 walking circuits calculated to be equivalent to an increased energy demand of 12 MJ per day, calculated using the estimates of Ribeiro, Brockway and Webster (1977), that energy expenditure is 2 J/kg B.Wt./m. moved horizontally and 26 J/kg B. Wt./m. moved vertically. In this experiment the mean body weight of the cows was 440 kg.

TABLE 1. COMPOSITION (g / kg), ESTIMATED ME CONCENTRATION (MJ / kg DM) AND MEASURED CP CONCENTRATION (g / kg DM) OF EACH DIET IN EACH OF EXPERIMENTS 1-3

Ration code:	Experiments 1	Experiment 2	Experiment 3		
	HR	HS1	HS2	DF	HP
Barley straw	300	170	*	*	*
Barley	230	455	–	–	–
Wheatfeed	220	100	–	–	–
Molasses	100	100	50	50	50
Soyabean meal	70	70	–	–	310
Megalac (80% protected fat)	15	15	–	–	–
Fishmeal		25	–	–	300
Molassed beet pulp	–			871	326
Urea	10	10	40	36	
Ground maize	–	–	431	–	–
Flaked maize		–	431	–	–
Salt	15	15	13	2.5	4
Dicalcium phosphate	15	15	22	30	
Calcium bicarbonate	20	20	5	3.5	3.0
Limestone	2.5	2.5	1	–	–
Vitamins & trace elements	2.5	2.5	7	7	7
ME (MJ/kg DM)	10.39	11.29	13.14	11.44	11.89
CP (%)	14.00	15.26	18.10	18.40	32.20
CP/ME	1.35	1.35	1.38	1.61	2.71

* Barley straw was offered *ad libitum* in addition to 4 kg/d (freshweight) of each diet.

A cross-over design was used for the experiment. The experimental treatments were a) walking (W) when cows were released from their stalls for approximately 3 hours to walk, or b) not walking (NW) in which the animals were kept in their stalls. There were two periods, each of three weeks. In the first period six cows walked, while the remaining six stayed in their stalls. The treatments were then changed over so that in the second period, the cows which walked in period one remained in their stalls, while the other six cows walked.

The animals were herded in a group of six and walked at their own pace with a two minute pause between each 440 metres. On day one they walked one third of the full distance, on day two, two thirds of the full distance and on day three and subsequent days they walked the full distance of approximately 9 kilometres. They showed no signs of stress. The cows were divided into two balanced groups according to milk yield and body weight in the week preceding the experiment.

Measurements made daily were milk yield and milk composition (fat, protein and total solids) and liveweight on two occasions per week. Refusals of food were collected before the morning feed, but these were small and effectively zero.

Experiment 2

Results of experiment 1 showed a substantial effect of exercise on lactational performance. The second experiment was designed to investigate the influence of diet composition on the response to exercise and to determine whether supplying a diet with a higher proportion of starch would have a moderating influence.

Twelve cows were used and after a four week adjustment period to diet, were divided into two groups according to milk yield and liveweight in the week preceding the formal experiment as in experiment 1. The diet treatments were randomly allocated to each group. One group received diet HR, rationed according to the same principles as in experiment 1. The second group received another complete pelleted diet, designed to have a higher starch content (HS1) (table 1).

The design of this experiment (and of experiment 3 which was the same) differed from that of experiment 1. In experiments 2 and 3 there were three experimental periods, each of three weeks. All twelve animals walked in the second (middle) period and did not walk in the first and third periods, which were control periods.

The exercise challenge was 10 circuits of the exercise path, equivalent to an average energy challenge per animal of 15 MJ per day. The higher energy challenge in experiment 2 was the result of the higher average body weight of cows in experiment 2. Animals in this experiment had a mean body weight of 530 kg.

Measurements were daily milk yield and milk composition (fat, protein and lactose), body weight twice a week and one blood sample (from the tail vein) once each week at 14.00 hours, less than one hour after the end of the walking period. Blood samples were refrigerated immediately and analysed using standard auto-analytical methods (Chemlab Instruments) in the Dalgety Dairy Health Recording Unit of the Veterinary Field Station, University of Edinburgh. Glucose, magnesium, phosphorus and urea were estimated by a continuous flow method, β-OH Butyrate by an automated colorimetric method and free fatty acids using a C-Test Kit (Wako).

Experiment 3

Experiment 2 showed that the nature of the diets used influenced some aspects of lactational performance when animals walked. The third experiment further investigated the effect of diet on the lactational response to exercise.

Twelve cows were used and divided into three groups balanced on the basis of milk yield and body weight in the week preceding the first treatment period, as in experiments 1 and 2. All animals received *ad libitum* barley straw, and each group received a different supplementary feed. The average dry matter of the straw was 938 g/kg fresh straw and the average chemical composition (g/kg DM) of straw was neutral detergent fibre 913, acid detergent fibre 603, hemicellulose 310, lignin 130, cellulose 462, residual ash 11, crude protein 33, ether extract 9 and ash 29. The supplements were designed to contain a high proportion of fermentable fibre (DF), rapidly fermentable carbohydrate (HS2) or digestible protein (HP). All diet supplements were designed to provide adequate rumen degradable protein and were offered at a fixed rate throughout the experiment.

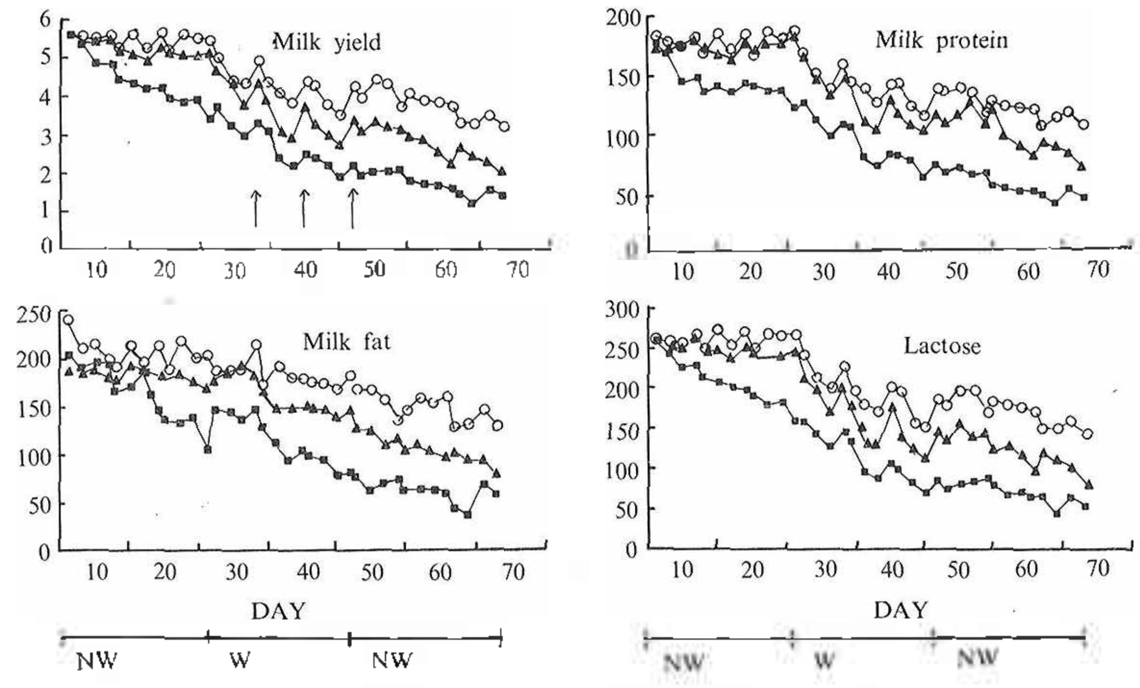
Four kilograms of each of the three diet supplements were offered each day to each cow in two equal meals at milking times, in the same bin in which the straw was offered. Straw was offered to the cows *ad libitum*. The daily allocation of straw was adjusted to allow refusals of between 10-20 percent per day.

The experimental design was the same as in experiment 2. The exercise challenge was 10 circuits of the exercise route, equivalent to an energy demand of 14 MJ per day. Animals in this experiment had a mean body weight of 500 kg.

A sample of blood from the tail vein was taken from each animal once each week at 14:00 hours, being less than one hour after the exercise period. Measurement of milk yield, milk composition and liveweight were as in experiment 2.

Statistical analysis

In experiment 1, a two way within-cow analysis of variance of period means (factors period and treatment) was carried out for milk yield and milk constituents. In experiments 2 and 3 a split-plot analysis of variance was carried out. The main plot (between cow) analysis assessed the effect of diet. The within-cow analysis compared the walking period data with the combined non-walking period data. The variation between the three periods was decomposed into a contrast between period 2 and the average of periods 1 and 3. Assuming a linear trend over the periods, this contrast should not be significant unless there is an exercise effect. Interactions between these contrasts and diet were also assessed. In experiment 3, data from a one week pre experiment period with all the cows fed a mixture of all three diet supplements was used as a covariate. Analyses of variance were made using GENSTAT 5 routines.



○ Diet DF	▪ Diet HP	▲ Diet HS2

Figure 1. Mean milk yield (kg / d) and yields of milk fat, protein and lactose (g / d) for cows fed high starch (HS2), digestible fibre (DF) and high protein (HP) diets in experiment 3 in each 21 day non walking (NW) and walking (W) period.

Results and Discussion

Experiment 1

Exercise significantly ($p < 0.01$) reduced mean daily yield of milk, milk protein and milk lactose (table 2). Milk fat yields were not affected, but the concentration of fat in milk was increased during exercise ($p < 0.001$) (table 3). Milk protein and lactose concentrations were not affected.

Walking had an immediate effect on milk yield and composition.

TABLE 2. MEAN YIELDS OF MILK (kg / d) AND MILK FAT, PROTEIN AND LACTOSE (g / d) FOR WALKING (W) FOR NON-WALKING (NW) GROUPS FOR EACH DIET OFFERED, AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN W AND NW DATA (P)

Experiment	Diet	Milk yield					Milk fat				
		NW	W	SED	df	P	NW	W	SED	df	P
1	HR	5.89	5.26	0.20	10	<0.01	233	228	8.3	10	ns
2	HR	7.32	6.62	0.26			289	297	12.1		
2	HS1	8.01	7.40	0.26			252	248	12.1		
Mean		7.67	7.01	0.18	20	<0.01	270	272	8.6	20	ns
3	HS2	4.67	4.28	0.31			155	161	11.6		
3	DF	2.88	2.48	0.31			110	111	11.6		
3	HP	4.02	3.65	0.31			164	181	11.6		
Mean		3.86	3.47	0.18	18	<0.05	143	151	6.7	18	ns

Experiment	Diet	Milk protein					Lactose				
		NW	W	SED	df	P	NW	W	SED	df	P
1	HR	171	156	4.7	10	<0.01	348	308	12.5	10	<0.01
2	HR	262	241	9.6			346	310	13.1		
2	HS1	291	271	9.6			383	351	13.1		
Mean		277	256	6.8	20	<0.05	364	330	9.2	20	<0.01
3	HS2	143	133	11.1			215	192	15.0		
3	DF	92	82	11.1			133	104	15.0		
3	HP	148	139	11.1			189	167	15.0		
Mean		128	118	6.3	18	ns	179	154	8.7	18	<0.05

There were no significant diet exercise interactions for any component.

Experiment 2

As in experiment 1, exercise significantly reduced milk yield ($p < 0.01$), milk protein ($p < 0.05$) and milk lactose ($p < 0.01$) yields, but did not significantly affect milk fat yield (table 2). Milk fat concentration showed a significant ($p < 0.001$) increase during exercise (table 3), but milk protein and lactose concentrations were not affected.

Significant diet × exercise interactions occurred with some blood metabolites, but there were no significant diet exercise interactions regarding the lactational response to exercise. Milk yield was greater in cows fed diet HS1 than HR (table 5), but this was not statistically significant. Fat concentration and fat yields were greater with HR than HS1, but these differences were not statistically significant. Both milk protein yield and milk protein concentration were greater with HS1 than HR. Milk lactose yield was greater with diet HS1 than diet HR, but lactose concentrations did not differ between diets.

In experiment 2, exercise increased the concentration of serum β-OH butyrate ($p<0.001$) and reduced plasma glucose and phosphorus concentrations ($p < 0.001$) and magnesium concentration ($p < 0.05$) (table 4). The effects on blood glucose were greatest in the first week of

TABLE 3. MEAN CONCENTRATIONS (g / kg) OF MILK FAT, MILK PROTEIN AND LACTOSE FOR WALKING (W) NON WALKING (NW) GROUPS FOR EACH DIET OFFERED AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN W AND NW DATA (P)

Experiment	Diet	Milk fat					Milk protein	
		NW	W	SED	df	P	NW	W
1	HR	40.0	44.3	0.6	10	<0.001	29.6	30.2
2	HR	38.7	44.5	1.1			36.6	36.5
2	HS1	33.5	34.8	1.1			38.9	38.1
Mean		36.1	39.7	0.8	20	<0.001	37.8	37.3
3	HS2	35.3	40.0	2.1			30.4	30.4
3	DF	35.1	42.4	2.1			35.0	34.4
3	HP	39.7	48.7	2.1			41.5	41.1
Mean		36.7	43.7	1.1	18	<0.001	35.6	35.3

Experiment	Diet	Milk protein			Lactose				
		SED	df	P	NW	W	SED	df	P
1	HR	0.6	10	ns	58.8	58.2	0.5	10	ns
2	HR	0.8			46.9	46.6	0.5		
2	HS1	0.8			46.5	46.0	0.5		
Mean		0.6	20	ns	46.7	46.3	0.4	20	ns
3	HS2	2.1			45.3	45.1	1.8		
3	DF	2.1			41.5	39.5	1.8		
3	HP	2.1			45.2	44.7	1.8		
Mean		1.1	18	ns	40.0	43.1	1.0	18	ns

TABLE 4. MEAN BLOOD METABOLITE CONCENTRATIONS FOR NON-WALKING (NW) AND WALKING (W) ANIMALS IN EXPERIMENTS 2 AND 3 AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN W AND NW DATA

Metabolite	Experiment	NW	W	df	SED	P
β-OH Butyrate	2	0.80	1.29	20	0.09	<0.001
mmol/l	3	0.48	1.17	18	0.08	<0.001
Glucose	2	3.93	3.57	20	0.10	<0.001
mmol/l	3	3.51	3.21	18	0.10	<0.001
Free fatty acids	2	NM*	NM	–	–	–
meq/l	3	0.61	0.96	18	0.10	<0.001
Magnesium	2	2.27	2.16	20	0.09	<0.05
mg/100 ml	3	2.13	1.86	18	0.09	<0.001
Phosphorus	2	7.33	6.20	20	0.49	<0.001
mg/100 ml	3	6.27	4.24	18	0.50	<0.001

* Not measured.

walking, suggesting a transitory impact of exercise on this metabolite.

There was a significant ($p < 0.01$) diet × exercise interaction effect on β-OH butyrate concentrations in the walking period of experiment 2. The increase in the walking period was greatest for cows fed diet HR compared with cows fed diet HS1. In the walking period, animals on the high roughage diet (HR) had average βOH-butyrate levels of 1.47 mmol/l compared with levels of 1.11 mmol/l in animals fed the high starch diet (HS1).

Diet also had a significant effect in experiment 2 on phosphorus concentrations in the walking period ($p < 0.05$). Phosphorus declined by 28% in cows fed the HR diet, compared with a decline of only 11% in cows fed the HS1 diet. As with βOH-butyrate, this indicates that diet can be used to reduce the impact of exercise on nutrient deficit during exercise.

Experiment 3

As in experiments 1 and 2, exercise significantly ($p < 0.05$) reduced milk yield with each of the three dietary treatments (table 2). The percentage change in milk yield with exercise was greatest with diet DF (14%, compared with 8% and 9% declines for cows fed diets HS2 and HP respectively), for which lactational performance overall was least). Exercise resulted in an increased milk fat concentration ($p < 0.001$) with all three diets (table 3), but with diet HS2 and DF. With diet supplement HP exercise resulted in a slight (non-significant) increase in yield of milk fat (table 2). Exercise did not affect milk protein or lactose concentration with any dietary treatment (table 3). Milk protein yield declined, but this was not statistically significant, whereas the decline in lactose yield was significant ($p < 0.05$. Figure 1 shows the changes in milk yield and milk fat, protein and lactose yields over the three periods.

Exercise increased concentrations of serum β-OH butyrate ($p < 0.001$) and reduced concentrations of plasma glucose, magnesium and phosphorus ($p < 0.001$) as in experiment 2 (table 4). Serum free fatty acids increased ($p < 0.001$). As in experiment 2 the effects on plasma glucose concentration and phosphorus concentrations appeared to be greatest in the first week of walking and thereafter reduced.

There were dietary effects on lactational performance (table 5) and blood metabolite concentration, such that in relation to the other diets HP sustained significantly ($p < 0.01$) greater rates of milk fat and protein secretion, as the result of enhanced concentration of fat and protein in milk. There was a dietary influence on milk yield in which diet HS2 sustained a higher milk yield ($p < 0.05$) than other diets.

The increases in βHB concentrations on walking were greatest for diet HP (172% increase for cows fed diet HP compared with 110% and 114% for cows fed diets HS2 and DF respectively). This interaction was almost statistically significant ($p=0.059$).

TABLE 5. MEAN MILK YIELDS (kg / d), MILK FAT, MILK PROTEIN AND LACTOSE CONTENTS (g / kg) AND MILK FAT, MILK PROTEIN AND LACTOSE YIELDS (g / d) FOR EACH DIET IN EACH EXPERIMENT AND THE SIGNIFICANCE OF DIFFERENCES BETWEEN DIETS IN EXPERIMENTS 2 AND 3 (P)

Experiment	Diet	Milk yield (kg/d)	Milk fat Content (g/kg)	Milk fat Yield (g/d)	Milk protein Content (g/kg)	Milk protein Yield (g/d)	Lactose Content (g/kg)	Lactose Yield (g/d)
	HR	7.09	41.0	291.4	36.6	255.1	46.3	333.7
	HS1	7.81	34.0	250.7	38.7	284.2	46.8	372.2
2	df	10	10	10	10	10	10	10
	SED	1.55	4.6	59.5	3.2	50.1	1.6	76.3
	P	ns	ns	ns	ns	ns	ns	ns
	HS2	4.54	36.9	157.1	30.4	139.9	45.2	207.3
	DF	2.75	37.5	110.3	34.8	88.3	40.8	123.0
3	HP	3.90	42.8	169.3	41.4	145.3	45.0	181.7
	df	8	8	8	8	8	8	8
	SED	0.5	3.4	20.9	4.0	16.4	2.0	25.5
	P	<0.05	ns	<0.05	ns	<0.05	ns	<0.05

A significant ($p < 0.001$) diet × exercise interaction was also seen with phosphorus concentrations. The proportionate effect of exercise on phosphorus concentration was less in cows fed diet HP than in cows fed diets HS2 and DF (a 17% change compared with 45% and 37% changes respectively).

The Effect of Exercise on Milk Yield and Composition

Milk yield was depressed by exercise by between seven and fourteen percent in these experiments. The results agree with those of Rizwan-ul-Muqtadir et al. (1975) who found that working caused a 14 percent drop in milk yield in working female buffaloes.

The levels of response demonstrated in the present experiments were lower than those of Barton (1987) who found that cows in Bangladesh in the second month of their first lactation lost between 23 and 40 percent of their milk yield. Similarly, Tornede (1939) reported that heavy work can cause up to an 80 percent fall in milk yield.

The variation in milk yield response over the full walking periods in the present experiments fell into patterns which were repeated in each experiment. The declines were greatest on the first walking days of each week. Over the three week walking period with two resting days between each five day walking period, an adjustment in the milk yield response to exercise was observed in which milk yield reduction was less in successive walking weeks. When animals were rested for two days, the yield recovered and then declined again when walking recommenced. The recovery of milk yield on resting days was very quick and after two days yields had often returned to the same level as at the beginning of the previous five day walking period.

The effect of exercise on milk yield over periods longer than three weeks was not investigated. Barton (1987) worked animals continuously for five weeks and found a greater milk yield decline than was demonstrated in the present experiments. This could be explained by the longer overall working period, the absence of resting days or by diet, which may have been poorer than in the present experiments. Rizwan-ul-Muqtadir et al. (1975) worked their animals continuously for 21 days and found a similar decline as in the present experiments.

When animals walked, lactose and milk protein yields declined, but milk fat yield remained relatively constant in walking and non-walking periods. These results differ from those reported by Rizwan-ul-Muqtadir et al. (1975) who recorded no effect on milk composition when animals worked, even though milk yield declined. Barton (1987) recorded no effect of work on solids not fat yield, but found an increase in milk fat content as milk yield declined.

Although there may have been an overall energy shortage or less than optimum metabolite balance for milk production during exercise, there was no shortage of energy or metabolites for milk fat production, which stayed relatively constant, presumably as a result of tissue fat mobilisation, as indexed by the increased free fatty acid concentrations in blood which were observed.

It is possible that differences between experiments in the response in milk fat concentration during exercise reflect the condition, or body composition, of animal subjected to exercise. Where reserves of body fat are substantial, then mobilisation also might be expected to be substantial, with consequent effects on milk fat concentration. But where body reserves of fat are low, then obviously, there is much less opportunity for this kind of response.

Milk protein yields were depressed by exercise. The protein content of the milk stayed relatively unchanged and as milk yield fell, so the yield of protein dropped accordingly. Since amino acid requirements for exercise are negligible (Lawrence, 1985; Pearson, 1986), it is difficult to ascribe the decline in milk protein to an amino acid deficit arising from exercise, although a reduction in amino acid availability consequent on enhanced demand for amino acids for gluconeogenesis could be a possible explanation.

Mean lactose yield declined by 11, 9 and 14 percent in each experiment respectively and this is most easily explained by a deficit of glucose and glucose precursors as a result of the greater demand for these during exercise. The contribution of glucose oxidation in skeletal muscle during sustained exercise increases by up to 38 percent (Pethick, 1984). Bird, Chandler and Bell (1981) showed that glucose uptake by the exercising hind limb of the sheep more than tripled in maintenance fed sheep and more than doubled in sheep fed at 1.5 maintenance relative to the resting hind limb. The most important limiting factor to milk yield in the present experiments appeared to be the availability of lactose precursors, which conforms to the hypothesis that glucose supply is a major limiting factor to lactation in working ruminants (Leng, 1985). The particular diets in the present experiments which were designed to provide high levels of glucose precursors via propionate or starch sustained higher milk yields than diets of low glucogenic potential (HR, Experiment 2; DF, Experiment 3) offered under similar circumstances. In Experiment 3 in particular, feeding a diet of low glucogenic potential (DF) reduced milk lactose yields and concentration in contrast to the other diets, and even more so when the cows were subject to exercise. In general though, the effects of diet on lactational performance were at least as great as were the effects of excercise. Walking reduced outputs of milk, milk protein and milk lactose to similar extents, whether diets were designed to have either a high or a low glucogenic potential, so there were no diet × exercise interactions as far as these measures of output were concerned. As the diets themselves influenced lactational performance in line with expectation (milk volume, protein and lactose outputs were enhanced with high starch, rather than high fibre diets) the interpretation must be either that the increased energy supply demands of walking could be met non-specifically as regards source of metaboilic fuel or that, for these diets, supplies of critical nutrients (eg glucose) were always above a minimum threshold such that the additional demands of exercise caused no specific metabolic embarrassment.

The Effect of Exercise on Blood Metabolite Concentrations

The commencent of walking affected blood chemistry. β-OH butyrate and free fatty acids increased on all the diets when the animals walked and glucose, magnesium and phosphorus levels decreased when they walked.

The results of the present experiments are similar to the changes in blood metabolite balance found during exercise in cattle and buffaloes by Singh, Soni and Bhattacharyya (1968), Georgie, Sastry and Razdan (1970), Hays, Bianca and Naf (1978), Nangia, Rana, Singh and Ahmed (1978) and Upadhyay and Madan (1985). Resting levels were within normal ranges as reported by Baird (1977) and Swaid, Sing, Sastry and Georgie (1986).

One hour of exercise in oxen has been shown to affect levels of glucose, free fatty acids, β-OH butyrate and inorganic phosphorus (Pearson and Archibald, 1989), though the changes were short-lived and values had usually returned to resting levels by 75 minutes after exercise stopped. No effect was found by these authors on levels of urea and magnesium.

In fed lactating cows, β-OH butyrate levels are on average 0.42 mmol/l (Baird, 1977), but are quantitatively more important in starved lactating cows (2.86 mmol/l) when the contribution of free fatty acid to ketone production increases. In the present experiments blood concentrations of β-OH butyrate increased more on diets with a high fibre content than an high starch diets when animals walked and increased to approximately 1.6 mmol/l during walking. The increase in free fatty acids when animals walked was similarly greater for animals fed the high fibre diets rather than the high starch diets.

Blood glucose concentrations fell in the present experiments when animals walked, but the effect of exercise appeared to diminish with time. The greatest decrease of 21.9 percent was seen in experiment 2. The reduced effect in subsequent weeks may result from increased fitness and a lower energy expenditure for pulmonary and vascular activity. This explanation is supported by the work of Hays, Bianca and Naf (1978) who found that in oxen there was a training effect which resulted in a subsequent reduction in exercising heart rate, respiratory rate and rectal temperature. Fitter animals are also better co-ordinated and may waste less energy through stumbling and uncertainty of gait.

Decreases in phosphorus and magnesium were observed in the present experiments as a result of exercise and the changes in phosphorus depended on diet. Decreases in magnesium (and phosphorus in some animals) in working buffaloes were also reported by Agarwal, Singh, Agarwal and Dwaraknath (1982). These reductions may be related to the increased use of both minerals in the processes associated with increased energy metabolism during exercise.

We conclude from these studies that exercise has a rapid and pronounced effect on lactational performance, characterised particularly by a reduction in yield of milk, protein and lactose. This reduction can quickly be corrected when exercise stops, but was difficult to ameliorate by the dietary means adopted in these experiments.

Acknowledgements

We would like to thank Dr. A. J. Smith and Dr. R. Anne Pearson of the Centre for Tropical Veterinary Medicine for advice and criticism on the experimental procedure. Acknowledgements are due to Mr. R. Archibald and Mr. I. Campbell for their assistance with daily management of the animals and carrying out the daily exercise routine.

Literature Cited

Agarwal, S. P., N. Singh, U. K. Agarwal and P. K. Dwaraknath. 1982. Effects of exercise on serum electrolytes and their relationship in entire, castrated and vasectomised male buffaloes. Indian Veterinary Journal. 59:181-184.

Ahmed, A. 1978. Livestock in Bangladesh: Their present status and development strategy. Asian Livestock. 3:6-8.

ARC. 1980. The nutrient requirements of ruminant livestock. Agricultural Research Council/Commonwealth Agricultural Bureau, Farnham Royal.

Baird, G. D. 1977. Aspects of rumen intermediary metabolism in relation to ketosis. Biochemical Society Transactions. 5:819-827.

Barton, D. 1987. Draught animal power in Bangladesh. Ph.D. Thesis, University of East Anglia.

Bird, A. R., K. D. Chandler and A. W. Bell. 1981. Effects of exercise and plane of nutrition on nutrient utilization by the hind limb of sheep. Australian Journal of Biochemical Science. 34:541-550.

Georgie, G. C., N. S. R. Sastry and M. N. Razdan. 1970. Studies on the work performance of crossbred cattle II. Some physical and chemical responses of blood. Indian Journal of Animal Production. 1:115-119.

Gee, M. R. 1983. Current status of research on animal traction. Animal World Review. 45:2-17.

Hays, F. L., W. Bianca and F. Naf. 1978. Effects of exercise in young and adult cattle at low and high altitude. International Journal of Biometeorology. 22:147-158.

Jabbar, M. A. 1980. Draught power shortage and mechanisation of tillage in Bangladesh. Bengal Journal of Agricultural Economics. 3:1-26.

Jarrett, I. G., O. H. Filsell and F. J. Ballard. 1976. Utilization of oxidisable substrates by the sheep hind limb: Effects of starvation and exercise. Metabolism. 25:523-531.

Kibria, Q. C. 1982. Draught animal power for crop production and use of cows. In Maximum production from minumum land. Proceedings of the 3rd seminar held in Mymensyngh, Bangladesh.

Krautforst, J. W. 1947. Influence of work balanced by food on the efficiency of cows. Animal Breeding Abstracts. 16:115.

Kuhn, N. J. 1983. In: Biochemistry of Lactation pp. 159-176. Ed. Mepham, T.B. Elsevier, Amsterdam.

Lawrence, P. R. 1985. A review of the nutrient requirements of draught oxen. In Draft Power for Production, ACIAR Proceedings. 10:59-63 [J. W. Copland, editor], *Queensland, Australia*, James Cook University.

Leng, R. A. 1980. Nutrition of ruminants at pasture in the tropics: Implications for selection criteria. Proceedings of the fourth World Congress on Genetics Applied to Livestock Production. Vol. 14. pp. 298-309 (W. G. Hill, R. Thompson and J. A. Woolliams, editors), Edinburgh.

Leng, R. A. 1985. Muscle metabolism and nutrition in working ruminants. In Draft Power for Production, ACIAR Proceedings. 10:69-77 [J. W. Copland, editor]. Queensland, Australia. James Cook University.

Lindsay, D. B. 1959. The significance of carbohydrate in ruminant metabolism. Veterinary Reviews and Annotations. 5:103-128.

Munzinger, P. 1982. *Animal traction in Africa*. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) Eschborn, W. Germany.

Nangia, O. P., R. D. Rana. N. Singh and A. Ahmed. 1978. A note on draught capacity in castrated and entire male buffaloes as reflected by some blood constituents. Animal Production. 27:237-240.

Pearson, R. A. 1986. Feeding and management of draught animals: a review. Indian Journal of Animal Production Management. 2:48-69.

Pearson, R. A. and R. A. Archibald. 1989. Biochemical and haematological changes associated with short periods of work in draught animals. Animal Production. 48:375-384.

Pethick, D. W. 1984. Energy metabolism in skeletal muscle. *In Rumen physiology: concepts and consequences* [S. K. Baker, J. M. Gawthorne, J. B. Mackintosh and D. B. Purser editors] Perth, Australia, University of Western Australia.

Pethick, D. W., N. Harman, J. K. Chong. 1987. Non-esterified long chain fatty acid metabolism in fed sheep at rest and during exercise. Australian Journal of Biological Sciences. 40:221-234.

Rajapurohit, A. R. 1979. Crossbreeding of Indian cattle: an evaluation. In Economic and Political weekly. A Sameeksha Trust Publication. Delhi.

Ribeiro, J. M. de CR, J. M. Brockway and A. J. F. Webster. 1977. A note on the energy cost of walking in cattle. Animal Production. 25:107-110.

Rizwan-ul-Muqtadir, R. A. Gill, M. Ahmad and Z. Ahmad. 1975. Draught power and its effects on milk yield and milk composition in lactating buffaloes during the winter season. Pakistan Journal of Agricultureal Science 121:93-98.

Singh, S. P., B K Soni and N. K Bhattacharyya. 1968. Haematological changes evoked by exercise in walking buffales. Indian Veterinary Journal. 45:212-216.

Swaid, A H, R. A. Sing, N. S. R. Sastry and G. C. Georgie. 1986 Blood composition profiles of zebu-taurus crossbred cattle and its management implications. Indian Journal of Animal Science. 56:1077-1085.

Tornede, H. 1939. The problems of work performance of dairy cows with special reference to hill cattle. Zuchtungskunde, 14:308-333. *Animal Breeding Abstracts.* 8:230. 1940.

Upadhyay, R. C. and M. L. Madan. 1985. Studies on blood acid-base status and muscle metabolism on working buffaloes. Animal Production. 40:11-16.