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Nutritional implications of work in draught animals

BY R. ANNE PEARSON AND JEROEN T. DIJKMAN

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

Draught animals have not been used to any great extent in agriculture in the developed countries since the introduction of tractor power in the 1930s and the rapid expansion of agricultural mechanization over the succeeding decades. In the Third World, however, draught-animal power continues to make an important contribution to rural and urban economies. In fields that tractors cannot reach, such as terraced hillsides, and on farms where the size and scale of enterprise, as well as finance, rule out tractors, animal power is the farmer's only means of cultivating the land, other than by hand. It is difficult to see farmers replacing animal power by mechanical power in these situations. Indeed, some areas of the world have experienced an expansion in the use of animal power over the last two decades. In parts of sub-Saharan Africa for instance, where human power has tended to predominate in agriculture, disease control and prevention measures have now extended the areas in which animals can be kept and they are replacing human power for many of the tasks involved in land cultivation.

Until relatively recently feeding working animals was an empirical business. Only during the last 15 years have scientists begun to obtain systematic information on the nutritional implications of work on draught animals. One of the main research topics has been to measure energy expenditure of draught animals so that their requirements can be quantified to the same extent as those of other classes of livestock. Other investigations have centred on the supply of nutrients to meet these requirements. Ruminants have received the most attention as they are numerically the most important draught animals (Ramaswamy, 1985). Cattle are used on many small farms in Africa, Asia and parts of Latin America. Water buffaloes are important in the more humid areas. Interest in the nutrition of working horses and donkeys, as opposed to the needs of horses in sport, has increased (Fielding & Pearson, 1991). Camels, elephants, mules, yaks, llamas, and some sheep and goats are also used as draught animals in a variety of different operations, from transport and cultivation to harvest operations and water lifting. The nutritional implications of work in these animals is less completely understood than those for cattle and buffaloes.

In recent years there has been an increasing move towards the use of cows for work on many smallholder farms (Matthewman, 1987). In areas of constant feed shortage, for example in parts of Bangladesh, females are replacing male work animals, thus removing the need to maintain draught oxen on the farm. In other areas where draught animals are

in poor condition at the start of cultivation, for example in parts of southern Africa, female animals are used alongside males to provide sufficient power to enable tasks to be completed on time. Research interest has centred on the partition of nutrients between work, lactation and reproduction and the long-term consequences of work by draught cows, and how best to satisfy their nutritional requirements.

In the present paper the effects of work on nutrient requirements, nutrient supply and the consequences for other productive functions are discussed.

NUTRIENT REQUIREMENTS IN WORKING ANIMALS

The major needs of the working animal are for energy-yielding nutrients. Changes in protein requirement associated with work in adult animals seem to be small (Clapperton, 1964; Pearson & Lawrence, 1992). Hence, requirements for protein-yielding nutrients are likely to be important only as glucose precursors, contributing to ATP production through direct oxidation, or in their role in enhancing digestion of poor-quality roughages.

There is no clinical evidence that significant deficiencies in specific amino acids, minerals and vitamins occur in draught animals as a result of working over prolonged periods in the year. Work does not appear to affect vitamin and mineral requirements greatly other than by a possible increase in the requirements for those minerals associated with the supply of energy to muscles (Ca, Mg and P) and the production of saliva and sweat (Cl^- , Na^+). In many places salt is fed to draught animals by farmers to supplement animal feed (Bamualim & Kartiarso, 1985; Gatenby *et al.* 1990; Matthewman & Dijkman, 1993) and to counteract the mineral losses during work. A point often made is that any increased requirement for protein, vitamins and minerals is likely to be met by the extra intake of feed needed to meet the increased demand for energy (Mathers, 1982; Bamualim & Kartiarso, 1985; Lawrence, 1985). In cases where body reserves are mobilized to support the increased metabolism resulting from work, however, the situation might be different. Depressed performance due to mineral deficiencies often do not become apparent until a diet is balanced by supplementation, and supplements generally help to improve production of all classes of livestock (Winugroho, 1989).

The problem in determining the energy requirement of draught animals has been the difficulty of measuring energy expenditure in animals that are not normally stationary. Brody (1945) suggested increasing the energy allowance of horses by 0.1 of their maintenance requirements for each hour of field work. More recently the net energy costs of the various activities which occur during work, such as walking, carrying loads, pulling loads and walking uphill and downhill, have been measured in the laboratory for several of the species used for draught purposes: cattle, buffalo, donkeys, camels (Table 1). If the total work done, distance travelled, height climbed and live weight of the draught animals is then measured in the field the total net energy for work can be estimated (Lawrence & Pearson, 1985; Lawrence & Stibbards, 1990). Using this technique, estimates of the energy requirements of draught animals have been obtained under a range of different circumstances (Lawrence, 1985; Lawrence & Pearson, 1985; Pearson, 1990). The major disadvantage of this technique is that the energy cost of walking has to be assumed. It is not constant but is affected by the condition of the terrain the animal is walking over. The energy costs of pulling loads, carrying loads and

Table 1. *Published values for energy expenditure for walking and carrying in draught animals and for the efficiency of doing work*

Activity	Mean energy expenditure	Animal(s)	Reference
Walking (J/m per kg live wt)	1.9	Cattle (<i>Bos taurus</i>)	Brody (1945)
	2.1	Brahman cattle/water buffaloes	Lawrence & Stibbards (1990)
	0.97	Donkeys	Dijkman (1992)
	2.0	Camels	Rose <i>et al.</i> (1992)
Carrying loads (J/m per kg carried)	2.6	Brahman cattle	Lawrence & Stibbards (1990)
	4.2	Water buffaloes	Lawrence & Stibbards (1990)
	1.1	Donkeys	Dijkman (1992)
Efficiency of doing work (kJ work done/kJ energy used)	0.30	Brahman cattle	Lawrence & Stibbards (1990)
	0.37	Buffaloes	Lawrence & Stibbards (1990)
	0.38	Donkeys	Dijkman (1992)
Raising body wt	0.36	Brahman cattle and Brahman × Friesian cattle	Thomas & Pearson (1986)
	0.35	Cattle	Agricultural Research Council (1980)
Walking downhill (J/m per kg live wt) slope: -10%	0.55	Donkeys	Dijkman (1992)
	0.67	Donkeys	Dijkman (1992)

walking uphill in the individual species are less of a problem. They remain relatively constant under most working conditions because, apart from the design of the pack saddle, in the case of animals carrying loads, they tend to be unaffected by external influences (Lawrence & Zerbini, 1993).

To solve the problem of extrapolating laboratory measurements to the field situation considerable effort has recently been put into the development of reliable instruments to measure O₂ consumption directly in the field (Dijkman, 1989; Lawrence *et al.* 1991; Zerbini *et al.* 1992). This equipment has enabled energy expenditure to be measured more precisely in animals working under field conditions and, hence, takes into account the variable factors influencing energy requirements such as ground surface and other environmental factors. It has enabled Dijkman (1993) to measure the energy costs of Bunaji (*Bos indicus*) bulls walking on different surfaces in the sub-humid zone of Nigeria. He found that the animals used up to four times as much energy walking on waterlogged ground compared with walking on dry firm ground (Table 2). The values for walking on firm ground were less than those recorded in oxen walking on treadmills in laboratories (Lawrence & Stibbards, 1990). Zerbini *et al.* (1992) in their field studies also measured energy costs of walking. They reported values for oxen walking on a level soil track that were about 39% higher than the measurements obtained on treadmills by Lawrence & Stibbards (1990).

Draught animals seem to require more energy for maintenance than non-working animals. Lawrence *et al.* (1989a) found that the energy expenditure of oxen on a

Table 2. *The energy cost and speed of walking of Bunaji draught bulls on soils of different consistency in the sub-humid zone of Nigeria*

Soil	<i>n</i>	Average energy for walking (J/m per kg)	SE	Statistical significance of difference	Average walking speed (m/s)	SE	Statistical significance of difference
Upland: Unploughed	38	1.47	0.03		0.97	0.08	
Ploughed	17	2.87	0.10	***	0.83	0.08	**
Dry fadama: Unploughed	13	1.76	0.07		0.87	0.05	
Ploughed	15	3.76	0.32	***	0.74	0.05	**
Wet fadama: Unploughed	19	3.30	0.14		0.80	0.04	
Ploughed	18	8.58	0.53	***	0.65	0.06	***

Values for ploughed soils were significantly different from those of unploughed soils: ** $P < 0.01$, *** $P < 0.001$.

poor-quality diet remained higher for up to 17 h after work. Lawrence *et al.* (1989b) determined the underlying resting metabolic rate during work by extrapolating to zero the rate of energy expenditure when oxen worked at different speeds. They observed that the average 'standing' value was 26% higher than that on non-working days. These two observations imply an increase of about 10% in net energy for maintenance on days on which oxen work.

NUTRIENT SUPPLY IN WORKING ANIMALS

Supplying draught animals with feed of sufficient quantity and quality at the right time to meet requirements for work is probably the most universal problem that faces farmers keeping draught animals. The start of the cultivation season is usually the time when feed stocks are at their lowest, particularly in areas where the dry season is long, and yet this is the time when draught-animal feed requirements are greatest. The common feeds available to draught animals are the grasses and the residues of cereal crops such as maize, millet and sorghum stover and rice straw, fed either on their own in cut-and-carry systems or to supplement grazing when that is available on rangeland, roadsides or field edges. The diets of draught animals are, therefore, characteristically high in fibre and low in N, with a metabolizability rarely above 0.4 for most of the year. Animals have enough difficulty eating sufficient of these diets to meet their maintenance requirements, without meeting any extra demands for work.

This has led scientists to study the effects of work on intake and digestibility of feed by both ruminants and equids. The nature of the diet appears to be a major determinant of the response recorded. In equids, Orton *et al.* (1985) found increases in food intake over resting levels of 2–27% when horses were exercised at 3.3 m/s (trot) for 1 h/d. Their horses consumed a chopped oaten-hay-based diet (dry matter (DM) digestibility coefficient of 0.68). On less-digestible diets, Pearson & Merritt (1991) failed to record any increase in the intake of donkeys exercised at 1 m/s for 4 h/d. Their animals consumed hay or straw diets with DM digestibility coefficients of 0.55 and 0.47 respectively. Several workers have reported increased digestibility of feed by 6–20% as a result of light exercise in equids (Olsson & Ruudvere, 1955; Orton *et al.* 1985; Worth

et al. 1987; Hintz, 1988). These diets were of relatively good quality, compared with the diets generally fed to draught animals.

The hypothesis that work may stimulate appetite, because it produces an increase in energy demand, has been more difficult to assess in draught ruminants. Although it may stimulate appetite, this effect may be counteracted by the reduced time available for eating that often occurs on working days. The stress of working, particularly in hot conditions, may also lower intake indirectly by reducing the animal's desire to feed immediately after work. Several researchers have shown similar or reduced intakes of roughage diets by draught ruminants on working days compared with non-working days. Buffaloes in Thailand (Wanapat & Wachirapakorn, 1987) and in Indonesia (Bamualim & Ffoulkes, 1988) consuming rice straw and field grasses, oxen in Nepal consuming rice straw and concentrate supplement (Pearson & Lawrence, 1992) or rice straw and tree fodder (Pearson, 1990) and oxen in Costa Rica consuming poor hay and concentrate supplement did not increase their intake during working periods in response to the increased nutrient demands of work. Animals tended to lose weight. Results of studies where the time of access to feed by both working and non-working animals has been standardized have given conflicting results; Winugroho (1990) reported increased intake by working animals, whereas Bamualim & Ffoulkes (1988) reported little difference. Bakrie *et al.* (1989) found cattle and buffaloes working for 3 h/d consumed more sorghum hay supplemented with urea and minerals when pulling a loaded cart than when pulling an empty one. No values were available for resting animals.

Although little increase in intake occurs during working periods, intake in the week immediately after a working period is often higher than that in the prework week (Pearson & Lawrence, 1992). This suggests either some form of compensatory intake to account for weight loss during work, or that during a working period ruminants may change their behaviour to attempt to compensate for the reduced time available for eating. Evidence for the latter has been provided by a study of feeding behaviour (D. G. Smith, personal communication) which showed that draught ruminants increased their rate of eating, rather than changing time spent eating or ruminating, to compensate for reduced time of access to feed. The finding that animals showed the same response after a similar period of feed restriction without work suggested that it was a response to restriction of time available for eating rather than a response to work itself.

A consistent feature of working ruminants seems to be a reduction in the rate of passage of digesta through the gastrointestinal tract. Ffoulkes *et al.* (1987) reported reduced rates of passage of Cr₂O₃, a non-specific marker, in working buffaloes compared with buffaloes at rest. Pearson & Lawrence (1992) using Cr-mordanted hay fibre, a solid particle marker, and Co-EDTA, a liquid-phase marker, observed a similar effect in working oxen on a rice-straw diet supplemented with some concentrate. This was associated with an increase in apparent digestibility of organic matter in working weeks. However, consistent effects of work on apparent digestibility and gastrointestinal time are not always seen in oxen (Pearson & Lawrence, 1992) or buffaloes (Bamualim & Ffoulkes, 1988) on fixed dietary allowances.

The studies reported previously all refer to adult male, castrate or non-productive female draught animals. Milking cows seem able to increase intake in response to work even when consuming hay diets. Lawrence & Zerbini (1993) report studies in Ethiopia in which intake of natural pasture hay was greater for working cows (72 MJ metabolizable energy (ME)/d at 90 d postpartum) than for non-working cows (60 MJ ME/d at 90 d

postpartum). Milk production was similar for working and non-working cows, 5 kg/d at 90 d postpartum. It was not clear whether the increased intake occurred on all days or whether, as observed in other cattle (Pearson & Lawrence, 1992), the increase occurred in the immediate post-work periods. The cows did not work every day but only 50 d in the 90 d period being considered. The increased intake in the working cows was not sufficient to meet entirely the additional energy requirement for work and the cows lost weight.

Taking all the various studies into consideration the general conclusion would seem to be that if draught animals are given almost entirely high-fibre roughage diets, low in N, then the food intake and gastrointestinal rate of passage of food are both likely to decrease, except, possibly, in draught cows. Changes in digestibility are unlikely to compensate for decreases in intake. Similarly, any increase in feed intake in draught cows that does occur is unlikely to be sufficient to meet entirely the additional requirements for work. Hence, in order to meet energy requirements for work, to minimize weight loss and maintain work output during the working season, the quality of the ration given to a working draught animal, whether it be a cow, an ox, a buffalo or a donkey, needs to be improved.

Most working animals lose weight. This can be tolerated if work seasons are short. Weight losses can be made up as quantity and quality of grazing and browse improve on a farm over the rainy season and work demands decrease as crops are sown. However, if animals are also used for transport, the work season can extend over most of the year. The working animal then has little or no off-season rest period in which to replenish its body reserves. Moreover, with more land taken into crop production in many farming systems as a result of increasing human population pressure, animals in areas with one distinct cropping season are likely to suffer food shortages in the wet season rather than in the dry season. In the dry season there is normally enough bulk food available from crop residues and fallow land, but with grazing areas declining in the wet season the possibility of replenishing body stores can become increasingly difficult. Similarly, cows that are expected to work and produce a calf have little opportunity to gain weight lost during work. In these cases the aim should be to provide enough nutrients in the feed to maintain live weight over the year. From data available on intake and estimates of energy expenditure during work, Lawrence (1990) calculated that if an ox worked an average day of 5.5 h then it would have to receive a diet with more than 9 MJ/kg DM in order not to lose weight.

UTILIZATION OF NUTRIENTS IN WORK AND THEIR PARTITION BETWEEN WORK AND OTHER PRODUCTIVE FUNCTIONS

Measurements of work output and speeds of working by draught animals (e.g. Lawrence, 1985; Barton, 1987; Pearson, 1989) and blood lactic acid concentrations (Martin & Teleni, 1989; Pearson & Archibald, 1989) indicate that for most of the time aerobic oxidation of substrates is the dominant pathway for ATP generation when draught animals are working. Studies of substrate utilization by resting and exercising muscles in equines and in ruminants (Bird *et al.* 1981; Teleni, 1984; Oddy *et al.* 1985; Pethick *et al.* 1987, 1991) have shown that glucose oxidation in muscles is obligatory and long-chain fatty acids (LCFA) are the other major fuel. Evidence is also available to suggest that the mobilization and subsequent contribution to oxidation of LCFA, and

ketone bodies, increases as work continues (Rose *et al.* 1977; Pethick, 1984). Equine muscle has a high capacity for glycogen storage (over 126 mmol/l) which provides considerable glucogenic reserves (McMiken, 1983) and most circulating glucose is absorbed directly from the gut in the horse. In the ruminant glucose availability is limited (Leng, 1970), largely because the ruminant is dependent on hepatic gluconeogenesis from volatile fatty acids to provide most of the circulating glucose and glycogen reserves (Judson *et al.* 1976). For this reason LCFA are thought to have a particularly important role as energy providers in the ruminants (Teleni & Hogan, 1989).

The uptake of acetate by ruminant muscle is highly diet dependent. High-roughage diets encourage the production of acetate in the rumen. Low feed intakes by the animal would result in a low uptake of acetate by the muscle. High feed intakes would be expected to increase acetate uptake by the muscle. This effect does not appear to be exercise dependent (Teleni & Hogan, 1989).

The extent to which amino acids are oxidized in working muscles of ruminants is less clear, but Teleni & Hogan (1989) in a study of working buffalo suggest amino acids are catabolized and used as direct energy sources or as glucose precursors. In a mature male working animal it is probable that if there is a surplus of amino acids over requirement these will be used as energy-yielding nutrients. However, in lactating animals there is likely to be competition for glucose and glucogenic precursors between work and lactation, which may be detrimental to milk production.

Reports in the literature show a variable effect of work on milk production. Jabbar (1983) in Bangladesh suggested a fall in milk yield when cows are used for draught. Goe (1983) reported that on work days cows can show a 10–20% decrease in milk yield. Similarly Matthewman (1989), in a series of three experiments with Hereford × Friesian cows in late lactation, found that milk yield decreased by 7–14%, depending on diet during exercise equivalent to an energy demand of about 13 MJ/d. Yields of lactose and protein also decreased, but all levels recovered following 2 d of rest. Yield of milk fat remained unchanged with exercise. The nature of the dietary supplement did not seem to have any substantial influence on the impact of exercise on the lactational performance. Intake of a poorly digested forage (straw) in the presence of supplements designed to be ‘glucogenic’ (based on barley), ‘aminogenic’ (based on fishmeal), or ‘lipogenic’ (based on sugar beet) was not affected by exercise, and the nature of the dietary supplement did not seem to have any substantial influence on lactational performance. The main conclusion from these experiments was that the lactating cow deals with a shortage of nutrients created through exercise by restricting secretion of protein and lactose whilst maintaining fat output. It appeared in these cows in late lactation that the nutrient shortage was not overcome by increased intake when the only food available was a poor-quality forage.

The picture in early lactation may be a little different. Rizwan-ul-Muqtadir *et al.* (1975) in Pakistan found no reduction in daily milk production during work. Zerbini (1991) in Ethiopia found that work (4 h/d pulling sledges at an average draught force of 400 N for 4 d/week) did not have a marked effect on milk production when crossbred dairy cows worked over a period of 90 d, starting 2 weeks after calving. However, he noted that work had a dramatic effect on cow weight loss. At 3 months after giving birth, working cows had lost an average of 26 kg, whereas non-working cows had lost less than 11 kg. This was despite the fact that working cows increased their intake in an attempt to sustain milk production and meet the energy demands of work (ILCA, 1990; Lawrence

& Zerbini, 1993). Over a 2-year period non-supplemented working cows continued to lose body weight and stopped milk production and reproductive functions in order to perform work. Supplemented working cows were able to perform work and produce milk with an acceptable loss of body weight (Lawrence & Zerbini, 1993). Excessive weight loss when cows or buffaloes are worked in lactation can result in reduced ovarian activity (Bamualim *et al.* 1987), reduced conception rates (Jainudeen, 1985) and longer calving intervals (Robinson, 1977; Petheram *et al.* 1982).

Clearly if a cow is to be used for work, and to produce a calf and a good supply of milk then it needs good-quality feed. In a study in Costa Rica, cows in mid-lactation needed feed energy equivalent to 2.2 times maintenance to work and maintain milk production (Lawrence, 1985). In virtually all circumstances to achieve an energy intake to meet requirements for work, lactation and maintenance of live weight, supplementation of the basal diet with some concentrates is needed (Zerbini, 1991). In practice many farmers are not able to feed their cows at the level required and will have to accept that if their cows work for a continuous period, they are unlikely to maintain production.

CONCLUSIONS

The major nutritional consequences of work are an increase in the energy requirements of a draught animal both for work and, it appears at some feeding levels, for maintenance. Estimates of energy requirements for work, based on measurements of work output in the field and energy costs of work on treadmills, suggest that the extra energy consumption for work is relatively low, up to 1.8 times maintenance for oxen and buffalo. The exceptions may be for large draught horses working for 7–8 h/d. Here values of 2.4 times maintenance have been calculated. The development of instruments which allow energy expenditure to be determined in the field will enable the energy requirements of draught animals to be defined more precisely. For instance, effects of ambient temperature, implement design and working practice on a draught animal's energy requirement can be more clearly quantified using these techniques. The consequences of work and different intensities of work on the resting metabolic rate, both in the short and long term, and effects of level of feeding can be further elucidated. Studies have tended to concentrate on the net energy requirements for work. Heat increment for work is generally assumed to be the same as for maintenance. There is, however, no firm experimental proof of this (Lawrence & Zerbini, 1993). This is an area which would seem to require further investigation to aid definition of feeding tables for draught animals.

One of the clear messages to result from investigations of the nutritional implications of work on draught animals is that although additional nutritional needs may be relatively low, the diets that are available to meet these requirements are usually of poor quality in the areas where most draught animals are found. Many diets barely meet requirements for maintenance let alone any extra requirements for work. The lack of any marked increase in intake, digestibility and utilization of feed as a result of work means that in order to meet requirements for work and avoid weight loss the feed quality needs to be improved. This is particularly true where cows are being used for work.

Considerable attention is now being given locally by scientists to enhance the quality of the diets available to draught animals and other animals on the farms. Emphasis is placed on better storage techniques for the staple feedstuffs, increased conservation of fodder

crops, treatment of forage and supplementation with browse, in addition to the use of urea and other supplements as they are available. Straight concentrate supplements are very often unavailable or too expensive to consider feeding on small farms other than on those with cash crops and a certain market.

Weight loss clearly has to be accepted in draught animals during the ploughing time at the end of the dry season, and when cows are worked in early lactation. The extent of weight loss that can be tolerated before performance is affected, and the interaction with body condition, are issues which would benefit from further study. Management practices that allow the animal to minimize weight loss and encourage repletion of reserves from feed, without compromising the needs for animal power to produce a crop, offer a challenge to the nutritionist as well as the farmer. Continued investigation of the nutritional implications of work on draught animals would still seem to be appropriate. It seems very likely that animals will continue to provide a considerable proportion of the power on small farms in the foreseeable future.

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