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G.P.O. Box 1571, Canberra, A.C.T. 2601

Copland, J. W. 1985. Draught animal power for production: proceedings of an international workshop held at James Cook University, Townsville, Qld, Australia, 10–16 July 1985. ACIAR Proceedings Series No. 10, 170 p.

ISBN 0 949511 17 X

Photos: Cover, p. 35, 161, Palitha Hadunge; p. 11, 121, 147, M. Wanapat; p. 57, 99, Colin McCool.

Draught Animal Power For Production

Proceedings of an international workshop held at James Cook University, Townsville, Qld, Australia 10–16 July 1985

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Foreword

The Graduate School of Tropical Veterinary Science of James Cook University was asked by the Australian Centre for International Agricultural Research (ACIAR) to host this workshop on Draught Animal Power for Production.

It is significant that the workshop was held in the tropical northeastern seaboard of Australia close to the nations of the South Pacific and South and Southeast Asia. These areas contain most of the large ruminants of the world and a major proportion of the draught animals. As well, scientists in Australia and the region already have strong links in research and development in the Asian countries.

The participants were constantly mindful that the purpose of the workshop was to find ways, through research, to increase production: production of animals, production of food crops, and production of wealth for the small farmer. The Recommendations section, we believe, reflects well on the hard work of all participants. It is to be hoped that many of these recommendations can be taken up and pursued with vigour.

In many Third World countries, a large part of the population depends on the draught animal as a source of power for the production and distribution of food. As populations increase and the land available per family decreases, the draught animal will assume even greater importance in many areas. The draught animals represent an additional source of income for the farmer through their use for hire and haulage.

However, the work output of draught animals may be limited because of poor nutrition, disease, or poorly designed harness and equipment. Furthermore the animal population is often smaller than desirable because of problems involving economics, genetics, and reproduction.

ACIAR was prompted, therefore, to invite James Cook University to organise this workshop to establish priorities for possible future research support in this area. The organising committee included representatives from the Commonwealth Scientific and Industrial Research Organization (CSIRO), and the Queensland Department of Primary Industries. The development of the program, identification of participants, and the organisation of the workshop became a joint responsibility of the three participating institutions.

Draught animals are an integral part of agricultural systems throughout many parts of the world. Despite their importance to agricultural production, particularly in developing countries, there is still a serious lack of reliable information on such factors as the importance of breeds, nutrition, disease, reproductive status, harness/ equipment design, and their socioeconomic impact in agricultural production systems.

ACIAR has received a number of requests from neighbouring countries for assistance in developing research programs on draught power. This workshop was organised to bring researchers from a number of countries with expertise in the problems of draught animal power into contact with Australian researchers who may be able to contribute to the solution of these problems. Recommendations from the workshop identifying priority areas for research in these areas are included elsewhere in this publication.

The success of the workshop was due in no small way to the hard work and quiet efficiency of a number of people. Members of the organising committee worked hard throughout the course of the discussions, and were assisted by support staff as follows: from James Cook University, Alison Healing, Phyl Medlen, Tony Boniface; from CSIRO, Margaret Allan; from ACIAR, Dr P. Mahadevan and Sylvia Hibberd. We are grateful to Reg MacIntyre of ACIAR for his role in the editing and production of this publication.

We hope that the workshop, and this publication, will stimulate the necessary interest in, and support for, research into draught animal power in developing countries.

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Recommendations

1. General

(i) There is a need to collect data on the effects of sociological structure, agronomic methods, physiology, nutrition, types of livestock, management, disease and engineering design on the efficiency of draught animal systems (DAS).

(ii) Data should be circulated more widely and rapidly by an international communications network linking Australia and countries dependent on draught animal power (DAP).

(iii) The economic importance of DAS should be defined and publicised.

(iv) Greater incentives should be given to scientists to work in the field of DAS.

(v) Investigate new applications for DAP, e.g. land improvement, water conservation and haulage, and transportation.

2. Socioeconomics

(i) Collection of data to define existing farming systems and the identification of priority problem areas for research. Within these priority systems, there is a need to select a target group of farmers for whom the research is designed.

(ii) Collection of data on the priority systems to identify potential biological and socioeconomic factors for improving farmer benefits from the DA enterprise.

(iii) Trials on farmers' animals to test new ideas/technology, and gauge farmer opinion/adoption. This approach should involve extension agencies as well as researchers.

(iv) There should be complementary experiments carried out on research stations.

(v) Developing demonstrations 'on farms' and mathematical models to help define national priorities for research, and convincing governments of the economic, social and other benefits that would flow from subsidising research support for the draught animal.

(vi) Take into account the other output of draught animals, e.g. milk, meat, calf crops, sub-contract work.

3. Physiology of Work

(i) The Workshop supports the need for physiological studies to assist in identifying superior breeds and individuals, to provide better training and to alleviate stresses caused by work. These should lead to greater work output with enhanced levels of reproduction and lactation and more humane treatment.

(ii) Record the present state of knowledge of the physiological changes occurring in the animal during work; develop conceptual models to quantify these changes.

(iii) Identify physiological limits to work output under realistic nutritional and environmental conditions.

(iv) Determine which physiological variables best indicate the extent of changes during work and recovery from work and relate them to environmental parameters.

(v) Develop portable equipment to record variables and test them under field conditions.

(vi) Develop standardised performance tests to assist in evaluating work capacity in draught animals.

(vii) Document ways in which animal behaviour can be used to indicate changes in the animal during work.

(viii) Study interactions between work and lactation, reproduction and disease.

4. Nutrition

(i) The Workshop recommends that strong emphasis should be placed on nutritional research as undernutrition is a major factor limiting the total draught system.

(ii) Establish within the farming enterprise under study the nutritional strategies required for survival, maintenance and production and the local nutritional resources available.

(iii) Estimation of the feeding value of available resources should be kept as simple as possible. Measurements should include at least in vitro organic matter digestibility, protein content and if possible essential nutrients such as minerals.

(iv) Desirable additional measurements would include ad libitum intakes without and with a comprehensive nitrogen, sulphur and mineral supplement and in vivo digestibility.

(v) Methods should be sought to predict nutrient supply from the simplest analytical data.

(vi) Despite limitations, metabolisable energy represents a useful basis for quantifying animal nutrition. Data should be sought to extend the capabilities of the present system and make it more applicable to the needs of DAP especially in relation to energy for work. There is a need for basic research on the metabolisable fuels used by working muscle. Feeds should be evaluated as sources of those fuels.

(vii) Methods should be sought to improve the nutritive value of available forages through conservation practices, supplementation and chemical treatments.

(viii) Support should be given to plant breeding to improve the nutritive value especially of cereal straws and to the introduction of improved pasture and browse plants.

(ix) Research should be conducted to define differences between buffaloes and cattle in:
—change in intake of forages of varying maturity in response to workload;
—applicability of dietary recommendations;
—dietary supplementation.

5. Genetics and Animal Breeding

(i) In view of the need to produce animals capable not only of work but also of the production of both milk and meat the Workshop recommends to ACIAR work aimed at implementing genetic improvement for multipurpose usage.

(ii) Within the proposed network for DAP research, efforts should be made to document existing systems in various locations and to determine whether genetic or environmental change is likely to improve draught power output.

(iii) Where a genetic change is required, comparative studies should be made of various genotypes to assess the possibilities of cross-breeding for required purposes compared with selection within existing and the derived populations.

(iv) ACIAR should support the identification of breeds based on the identification of specific desirable characters which may be useful in the region.

(v) ACIAR should also work towards encouraging governments to recognise the need for more long-term evaluation of local populations and breeding programs used to develop multi-purpose animals.

6. Reproduction

(i) Reproductive research is one method of arresting the current decline in animal numbers and increasing DAP in line with national goals.

(ii) Reduce conception failure by the following:
- (a) improve oestrus detection methods;
- (b) improve nutrition and encourage tactical nutrition for cycling;
- (c) encourage sociological factors that promote conception, e.g. night corralling;
- (d) consider synchronisation of oestrus only if it is economic;
- (e) determine the availability of bulls;
- (f) investigate bull fertility especially in communities with poor calving rates;
- (g) study genotype-ovarian function interactions;
- (h) apply new technology to the study of ovarian function.

(iii) Obtain more precise data on embryonic, neonatal and post-natal calf mortality and determine infectious causes (see also Section 7).

(iv) Determine the effect of heat and work stress on early embryonic death.

(v) Study management-reproduction interaction, e.g. body weight score and composition/ovarian function.

(vi) Develop mathematical models to determine optimal target weights for successful mating.

7. Animal Health

(i) While acute infectious diseases are clearly defined, subclinical conditions are poorly understood and require further research. They include haemoprotozoal and helminth infections.

(ii) Multidisciplinary research and extension teams should establish the socioeconomic importance of existing diseases with respect to draught power.

(iii) Economic control of disease by management strategies, vaccination and therapy should be improved and applied where possible.

(iv) Breed comparisons for resistance to particular diseases should be encouraged; e.g. trypanotolerance in cross-breeding schemes.

(v) Obtain farmer opinion and collect data on traumatic and other diseases that inhibit DAP.

(vi) Study interactions between the host, environment (including the work environment) and disease leading to decreased work output, low fertility and other production losses.

8. Engineering

(i) Despite considerable efforts to improve DAP design there is a need for further research on harness, ploughs, carts and other equipment.

Two aspects of engineering are recognised:

(a) Animals

(ii) Standardise techniques of measurement and definitions of work capacity, effects of slope, temperature, radiation, etc.

(iii) Establish response curves relating workload to increase of rectal temperature, etc., to determine stress.

(iv) Standardise descriptions and definitions of workload for draught species and breeds.

(v) Study the benefits of reducing radiant heat loads.

(vi) Note changes in conformation resulting from cross-breeding and anticipate any changes needed in harness design.

(b) Implements and Other Equipment

(vii) Basic research should be farm-oriented. Research workers should seek farmer opinion.

(viii) Determine factors limiting the application of successful new designs such as cost, availability of local materials and lack of incentives.

(ix) Study the effects of improved agronomic systems on DAS.

Socioeconomics of Draught Power

Socioeconomic Aspects of Draught Animal Power in Southeast Asia, with Special Reference to Java

R. J. Petheram,* Ashari Thahar and R. H. Bernsten*****

DRAUGHT animals are undoubtedly the most important consumers of feed and labour resources amongst the livestock of Southeast Asia, and play vital economic and social roles in the lives of millions of families. However, it is often difficult to separate socioeconomic factors from the complex of other factors in the analysis of Asian farming systems. The approach taken here is to discuss draught animal power (DAP) generally, and to describe some socioeconomic features common to DAP enterprises in SE Asia. Important variations between DAP enterprises are then illustrated by examining the case of DAP in Java and in three villages with differing farming systems. Socioeconomic implications in designing research on DAP, and appropriate approaches to research in SE Asian villages are discussed.

In this paper, only the use of DAP in land tillage is covered, as this accounts for the major part of animal power utilised in the wet tropics. Only cattle and buffalo are considered as these are the major draught animals in all SE Asian countries.

Significance of Large Ruminants

In most SE Asian countries the number and density of large ruminants exceeds the total of all other herbivorous livestock (i.e. small ruminants and horses). In terms of livestock units, large ruminants exceed small ruminants by a factor at at least 10. Consequently the quantity of feed consumed by large ruminants varies from 10 times as much (for Indonesia) to over 1000 times as much (for Thailand) as that consumed by small ruminants (see Table 1).

Although the proportion of large (to small) ruminants in many countries is decreasing (Winrock 1983) their overall importance is likely to remain far greater than that for small ruminants for many years. Of the roughages currently utilised, a large part is high-fibre residues (e.g., ricestraw) which at present can only be used by large ruminants.

Table 1. Densities and livestock unit ratios of large and small ruminants in some Asian countries.

	Density (no./km^2)		Unit* Ratio
Country	Large ruminants	Small ruminants	Large:Small
Indonesia	4.6	6.3	10:1
Malaysia	2.1	1.2	30:1
Philippines	16	5.1	50:1
Sri Lanka	26	8.2	50:1
Thailand	22	0.2	1840:1
India	74	35	35:1
Bangladesh	155	70	40:1

* Calculation based on approximate average herd liveweight ratio of one large ruminant to 15 small ruminants for Asian countries (calculated from Europa Yearbook 1984).

Socioeconomic Characteristics of DAP

Most draught animals are kept by small farmers i.e., families with small land and capital resources (Javier 1977). Small farmers in the wet tropics typically take part in both cropping and livestock enterprises, as well as other income-supplementing activities (White 1974). They invariably have few resources and are exposed to risk as a dominant management factor (Chambers and Ghildyal 1984). In Java some families have no land, but keep stock on communal grazing and crop residues (Thahar and Petheram 1983b).

Draught animal enterprises are closely interlinked with other enterprises, activities and resources of small farms. Their feed consists mainly of crop residues and forage or grazing from waste, fallow or common land. Banta (1972) examined various irrigated multiple crop systems and found that 60% of

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digestible protein produced was not usable by man, yet could provide feed for ruminants.

Large ruminants used for draught power invariably serve other important purposes on small farms—providing family security, milk, manure, meat for ceremonies, income from calves sold or rental to other farmers, and even entertainment (Robinson 1977b; De Boer 1984). It is difficult to ascribe a value to farmers of these alternative functions which animals perform. Costs involved in keeping animals are also difficult to calculate, especially where the opportunity costs of family labour and crop residues are very low (Bose and Clark 1970).

Farming Systems and DAP

There is large variation in the circumstances under which animals are kept and worked which is closely related to farming systems. Thus any serious DAP study should be carried out within a farming system framework, so that problems tackled and results of research have meaning to real groups of farmers or 'recommendation domains' (Byerlee and Collinson 1980; Simmonds 1984).

Various attempts have been made to classify farming systems and their livestock components in the Asian tropics (e.g. Crotty 1980; Winrock 1983; DeBoer 1984). Such classifications, however, are very general and attempt only to outline some main characteristics and linkages. More important than classification itself is that the farming systems for which DAP research is planned are defined in terms of criteria which determine DAP practices, animal and feed resources, physical demands on animals, and hence problems in improving DAP. In Table 4, three villages are described in terms of 13 criteria considered important in defining "domains" for DAP research in Java.

Alternative Power Sources

According to Giles (1975), animals provided 51% of the energy used on Asian farms (human 26%, and mechanical 23%). This estimate was biased by the power used for transport in countries like India and Bangladesh which have the highest DAP use in the world (FAO 1983; Sarker and Farouk 1983).

There is marked variation between areas in the relative use of hand labour, DAP and tractors. Most SE Asian villages have no tractors, yet in some areas (where farm sizes are large and cropping intensive) tractors have taken over a large share of tillage since the early 1970s. The density of draught animals varies from very low (e.g., less than 5) to over 100 head/km^2, well above the number required for tillage purposes (Falvey 1979; Huitema 1982).

Other factors which vary widely are the extent to which labour, animals and tractors are hired for farm operations. An example of this variation is shown for two West Java villages in Table 2. Data on elasticities of supply and demand for animal and manual labour (and tractor) are rarely available (Kasryno 1985).

The main reasons given for the introduction of tractors to rice-growing areas have been, (a) intensification of crop production (through improved crop turn-around time), (b) improved pest control (through synchronisation), (c) reduction in the drudgery of hand tillage, and (d) labour shortage. However, socioeconomic studies have seldom justified tractor use on these grounds in intensive rice-growing areas: on the contrary, there are reports of tractor introduction resulting in increased bottlenecks at land preparation, reduced crop yields (Sinaga and Bernsten 1981), displacement of labour and animals (Bose and Clark 1970; Bernsten and Rachim 1980) and benefits for the rich at the expense of the poor and landless (Gotsch 1973, Hurun 1981). Serious problems in tractor management and maintenance have resulted in some areas in a steady decline in tractor viability and in tractor numbers (Hafsah and Bernsten 1981).

The time and costs involved in land preparation by tractors, animals and human labour have been compared by several authors. Results of time studies depend largely on the type of tractor, and the average size of fields, while the comparative costs depend on interest rates applied to tractor

Table 2. Type of labour used by 30 farmers in two Krawang Villages.*

Village	Land Preparation														
	Man		Animal		Tractor		Planting		Weeding			Harvesting		
	F	H	F	H	F	H	F	H	F	C	H	F	C	H
A	8	92	35	65	0	100	5	95	8	28	66	7	28	85
B	17	83	1	99	6	94	7	93	21	0	79	8	0	92

* Figures are percentages of farmers in each village using labour in the categories: Family (F), Hired (H) or 'ceblokan' (C—weeding, giving the right to a proportion of harvest). From Bernsten and Rachim 1980.

loans and the life and area served per tractor (e.g. Kato et al. 1979).

Palis et al. (1980) found in Burma that the time involved in ploughing (14.7 hours) and harrowing (8.7 hours) using an 8.5 HP power tiller and harrow was significantly less than that for pairs of buffalo (or cattle) (22.7 and 22.0 hours) or a single buffalo (21.5 and 22.8 hours). Surprisingly there was no significant difference in time taken (or depth of ploughing) between the single and double animal teams. The average area covered by each pair of animals in Burma was calculated at 3.4 ha.

The economic viability of land preparation methods depends upon the costs of inputs and value of outputs. Bernsten (1981) pointed out that while in Indonesia hand tillage was cheaper than tractor use, this situation would be reversed if Indonesian farmers received tractors at Japanese prices and the Japanese (subsidised) price for rice. Similarly, the viability of DAP could be markedly improved by Government support measures (e.g. credit for draft animals, subsidised forage reserves, training and supply of good bulls).

DAP in Java

Java is an interesting case to study because it represents an area of high human and stock density, high cropping intensity and rapid urbanisation—states which are being approached by many other regions with exploding population growth. Information is mainly from Rollinson and Nell (1973), Robinson (1977a and b), Petheram et al. (1982), Tillman (1981), Thahar and Petheram (1983a and b), Huitema (1982) and Basuno and Petheram (1985).

The island of Java, which is only 6% of the total land area of Indonesia, has over 3.8 million cattle and 1 million buffalo, representing 60% of large ruminants in the country. In recent years there has been a decline in large ruminant numbers in many areas, associated mainly with the reduction in grazing area, increased frequency of family financial difficulty (and hence need to sell), and reluctance amongst young people to rear animals. Regulations prohibiting slaughter of young cows have not been rigidly enforced. Cattle and buffalo distribution in Java is shown in Table 3.

The percentage of families keeping large ruminants varies from less than 1% (e.g., in steep, upland villages) to over 90% in some East Java villages. Most buffalo are in (wetter) West Java and cattle in (drier) East Java, and nearly all are kept primarily for draught. The proportion of adults in most village herds is high (approximately 60%).

The average landowner has less than 0.5 ha of land and 40–60% of families have no land. The average number of draught animals kept per family is about two in most areas. This means that many farmers have to borrow adult animals to make up the pairs for work. Only in a few (light shallow soil) areas of West Java are singles (buffalo) used for tillage. Mainly adult females are kept, to diversify and maximise income (i.e., from draught and calf sales). In some villages mature buffalo bulls are very scarce, and herd survival rate is low (Petheram et al. 1982). Schemes for AI are successful in many areas for cattle, but not for buffalo. Draught animals in Java are not milked. In contrast to some other SE Asian regions where oxen are commonly used, castration is considered mutilation and not practised.

Both cattle and buffalo pull carts and drive sugar cane mills in certain areas, but the main use is for land preparation. In general, two ploughing and two raking/levelling operations are carried out on each wet rice field (taking 30–60 days/ha/pair). Maize lands require only about half this work. Often men work alongside animals, for rapid preparation and levelling of small rice fields. Most animal tillage is on levelled fields (sawah) which support mainly rice, but maize assumes dominance in large areas of East Java.

Table 3. Some characteristics of the three provinces of Java (1981).*

	West Java	Central Java	East Java	Indonesia
Cattle (head/km^2)	4	27	55	4.1
Buffalo (head/km^2)	11	9	5	1.3
Cattle + buffalo (LU/km^2)	11	26	40	2.8
Sheep + goats (head/km^2)	63	86	46	6.3
Total ruminants (LU/km^2)	15	43	46	3.2
Human density (per/km^2)	640	740	610	80
Area (%) with <2 dry months	50%	20%	5%	–
Maize cultivation (m^2 crop harvested/capita)	50	150	400	–

* LU = Livestock unit = 250 kg liveweight. A dry month is one with less than 100 mm rainfall. Bureau of Statistics (1982), Directorate of Food Crops (1982), and Juarini and Petheram (1983).

Generally, animals work between 3 and 6 hours/day, mainly in early mornings but sometimes in late afternoon. Some 'owners' can afford to work animals shorter daily hours, while people who rent out animals tend to work longer hours, and more days per year than average. The range of days worked per year is indicated in Table 4 for three example villages. Breeding is usually by natural mating while animals are grazing or being washed. However, in areas and seasons where animals are zero grazed, mating is arranged by rearers. A mating fee is seldom charged. Most work with draught animals is performed by adult men, although children are important in herding, and women often tend animals in home pens while animals are not grazing or working. Table 4 illustrates some main differences between three villages in terms of variables important in DAP. Soil type, crop, and irrigation affect workload on animals, and feed availability is a major determinant of quality of draught power in different seasons.

In Table 5 an approximate economic analysis of a buffalo renting enterprise is presented. It should be noted that most draught animals in Java work for less than half the (200-day) period used in this example.

Socioeconomic Factors in Planning DAP Research

If our aim in research is to improve productivity and efficiency through adoption of new technology by small farmers, then it is important that we understand the factors which influence adoption. The rate of transfer of new technology to small livestock enterprises in SE Asia has been notably slow (De Boer 1982). Many sociologists believe that this lack of change can be largely explained by the neglect of socioeconomic factors in research and development programs. A basic principle in Java, for instance, is that social obligations receive priority over economic interests and most farmers do not respond to economic incentives (Blom 1979).

Table 4. Summary description of three villages in Java for DAP purposes.

Criterion	Village I Serang	Village II Madura	Village III Bogor
1. Rainfall class Length of dry season (Dry month has $<$ 100 mm)	low 5–7 months	low 6–8 months	high 0–2 months
2. Irrigation	non-irrigated	non-irrigated	80% irrigated
3. Main crops and period	1 x rice (150 d) Dec–April	upland rice/maize cassava/beans Nov–April	3 x rice (3 x 100 d) vegs/roots
4. Duration and no. of work periods/year	1 x 30 d (Nov)	1 x 20 d (Oct–Nov) 1 x 15 d (Jan–Mar)	all year owners—50 d renters—200 d
5. Soil texture/depth of tillage	80% heavy/deep 20% medium/shallow	80% light/shallow 20% heavy/medium	medium/medium
6. Main feeding practice	all year grazing + (Dec–Mar)—weeds (Mar–May)—straw	hand fed all year 70% grass 20% stover 10% leaves	80% handfed gr. straw (60%) m. stover (10%) cut grass (30%)
7. Stock ownership/work arrangement	70% own 30% share	90% own 10% share	80% own 20% share
8. Animal species/breed (single or pairs)	swamp buffalo 80% pairs 20% single use	madura cattle pairs	swamp buffalo pairs
9. Other purposes of rearing	security calf sales manure use	calf sales security manure use	calf sales manure use security
10. Demand for rental	med–high	low	high
11. Density (head/km^2)	110	120	15
12. Net replacement rate*	105%	130%	40%
13. Farmer-stated DAP problems	animals too small	feed short (dry)	disease risk feed shortage (wet) bull shortage

* Average no. of female replacements in breeding life of 100 breeders.

Table 5. Summary economic analysis of buffalo rental enterprise (Java).

Capital invested	
Two adult cows valued at $300 each[a]	A$ 600
Capital value of pen (220), plough and harrow (80)	300
Annual costs	
Depreciation on pen, plough and harrow (5 year life)	$ 60
Interest on $900 capital (at 15%)	135
Labour for feeding/washing (3 h/d x 365 d at 10c/h)	110
Labour for working animals (5h/d x 200 d at 12.5c/h)	125
Medicines	10
Total	$ 440
Annual income	
Rental for 200 days at $4/day/pair	$ 800
Manure sales	100
Calf sales 1 x 150 kg calf	150
Total[b]	$1,050
Net annual income (2 animals)	$ 610

[a] The value of animals as family security (insurance and bank) is not taken into account. (Nor are the appreciation in value of animals while rearing, or losses through mortality.)

[b] Calculated in another way, the gross income of $1,050 gives a return to labour (262 days of 8 hours) of $4/day. This is well above the agricultural wage of $1.20/day (+ meals). This assumes owner performs all feeding, washing and working tasks personally (see White 1974).

The average small farmer is probably ready to embark on innovations only when these are very attractive, without risk, and socially acceptable. There is evidence that buffalo rearers in West Java are even more conservative (older and less educated) than the average farmer (Basuno and Petheram 1985). This, coupled with the greater difficulties that livestock rearers face in testing new ideas compared to crop farmers (Bernsten 1982), means that special approaches are needed in designing research aimed at improving DAP.

Somewhat contradictory to the theory that social rather than economic factors control farmer adoption (Blom 1979), is the economist's belief that small farmers are rational in their decision making, i.e. they will adopt a new idea if it is seen to be of benefit (Popkin 1979). Another principle to be recognised in DAP is that farmers cannot be expected to adopt new technology until, (a) they know of its existence, (b) they understand it, and (c) the benefits of adoption are clear. The implications here are that ideas intended for adoption by small farmers cannot succeed without effective scientist/ farmer communication (Vierich 1984).

In many 'wet tropical' areas livestock problems are regarded by farmers as less important than their cropping or other problems. This points to the need in DAP research for careful selection of both areas (villages) and farmers for farm research. The following guidelines apply to planning of all livestock component research for small farms in SE Asia:

1. The research should be related to an existing farming system and aimed to reduce well-established constraints in that system.
2. The research should be aimed at a particular target group (or recommendation domain, e.g. landless rearers who rent out buffalo for 200 days per year).
3. Research of a technical nature should be preceded by surveys of farmer circumstances, animal use and the farming system.
4. Facilities to test results of research (or ideas) on real farms must be available (e.g. an active extension or farming systems research agency).
5. Testing of new livestock technology on farms can seldom be done by conventional experimentation. Initially it involves feasibility testing, later comparison of performance of new technology with area norms, and finally adoption studies.
6. Research projects involving farmers from the start to finish are most likely to result in properly tested technology and farmer adoption (Chambers and Ghildyal 1984).
7. In DAP research, long-term studies are essential (Goe 1983).
8. Major criteria in selection of areas in which to work should be, (a) interest and cooperation of extension personnel, and (b) farmer cooperators can be critical. Younger, better-educated farmers with drive and influence should be included.
9. Research must consider stability, sustainability and equitability of systems.

Realistic Research Topics

In a survey of four villages in Java (Thahar and Ridwan, unpublished data) none of the 40 farmers interviewed felt that any direct income benefit could result from use of improved tillage implements. Most rearers stated that they had no major problems with their draught animal enterprises. One is led to contemplate Ruthenberg's saying: 'How can a farmer know what he wants if he does not know what he can get?' As there is little doubt that improved knowledge of nutritional and reproductive functions in working animals could help to improve DAP in the long run, basic research on these topics may be justified. The dilemma, however, is in how many resources to devote now to such basic research, versus research of an applied nature. Some of the problems perceived by farmers (e.g. feed shortages, disease problems) could be tackled now by adapting known technology on small farms. Many problems (e.g. lack of capital, inadequate size of animals, shortage of bulls) require government intervention as well as trials on farms. Three 'levels' of research emerge: (1) basic research, mainly on stations, (2) applied research on farms, (3) applied research with government interventions, and (4) research projects involving (1), (2), and (3).

The alternatives for improving DAP may be categorised under efforts to (a) increase numbers of draught animals, (b) increase numbers of rearers, (c) increase time worked per day or per year, (d) increase production (or management) efficiency of existing stock, (e) improve genetic potential of stock, (f) improve efficiency of implements, (g) improve feed supply from farming system, (h) reduce losses of animals through disease, (i) improve economics of draught enterprises by increasing income from alternative sources (e.g. milk or calf sales).

These categories, combined with the three levels of research outlined above, give rise to a vast array of possibilities for research. However, a main need is to attach research to broad-based programs of DAP improvement. Such programs need strong government support, with a major thrust involving research on farms. This approach requires personnel with a real interest in working with farmers, as well as appropriate equipment such as field vehicles, mobile workshop, and aids to communication with farmers.

Conclusion

Assuming that governments in SE Asia see equity and social justice as priorities in shaping future agricultural policy, then support for DAP appears to offer a realistic compromise between extensive mechanisation and the drudgery of hand labour. DAP has the additional advantages of low foreign-exchange costs, the promise of more efficient and flexible use of existing resources (crop, animal, human), and the inestimable value of animals as security and alternative income sources.

Because the future of DAP is so dependent on national policies there is an urgent need for advantages and improvement in efficiency of DAP to be clearly demonstrated to governments. Research on DAP must therefore be broad-based enough to include elements such as close farmer contact, mobile village research/training units, and direct communication with policymakers to provide the essential interventions. At this stage, support for purely laboratory-based research to study limited aspects of DAP can achieve little. Exceptions may be basic research on nutrition and reproduction of working animals, but research on these topics must be related to actual farming systems.

Research on socioeconomics of DAP should precede research on technical aspects. While there is a clear need to demonstrate the advantages of improved DAP practices and the fallacy of tractors as a panacea to farm production problems, the most important requirement may be for a systems approach to research. Perhaps the greatest potential for improving DAP is through increasing crop yields and hence total flow of energy and nutrients through systems. As tillage itself involves such vast expenditure of energy, any holistic approach must also consider non-mechanical ways of reducing the amount of time which farmers spend on weed control (Wijewardene 1981).

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Draught Animal Power—Socioeconomic Factors

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MIRACLES of science and technology in all human endeavours—atomic energy, electronics, communications, space travel, medicine, and so on—have revolutionised human life. In spite of these spectacular achievements, 2 billion people in developing countries (DCs) still depend on age-old draught animal power (DAP), and most will do for many years to come.

Draught animal power is not efficient in most developing countries, except in China. It was in that context that the United Nations Conference on New and Renewable Sources of Energy, held in Nairobi in August 1981, recommended that the productivity of the DAP system should be upgraded immediately in order to accelerate development (Ramaswamy 1981). In spite of the crucial role of DAP in development, Third World countries have yet to take interest and initiative in the modernisation of DAP by way of surveys, studies, research and development, policy formulations, resource allocation and action programs.

Animals used for draught power include cattle and buffaloes, horses and mules, donkeys and camels, yaks and elephants. DAP provides energy for the cultivation of nearly 50% of the world's cultivated area as well as for hauling over 25 million carts.

Modernising DAP

Mechanisation and automation are integral parts of development. It was, therefore, taken for granted that this antiquated and inefficient mode of power should be replaced with trucks, tillers and tractors. Therefore, proposals to modernise DAP, where it plays a dominant role, and to introduce it in certain regions of Africa, may appear anachronistic. In fact, one reason why developing countries do not take an interest is that they view DAP technology as backward and a retrograde step. Help offered by advanced countries, for improving DAP systems, is often misunderstood by Third World countries. Overcoming this problem is essential in developing successful modernisation programs.

Studies show that DAP is going to be the critical component for agriculture and rural development in most developing countries. In fact, attempts made by some African countries to bypass DAP, going from human to mechanised systems directly, have been largely a failure. Emphasis on high technology can continue in sectors where necessary; but, modernisation and/or introduction of DAP should no longer be neglected.

From technical and economic points of view, DAP is inevitable in certain situations and, in others, it is appropriate. In developing countries about 100 million farm holdings are less than 2 ha where tractors and/or tillers (T&T) are uneconomical and use of animal-drawn implements (ADIs) is inevitable. In India, the energy for ploughing two-thirds of the area cultivated comes from DAs. T&T becomes viable for holdings above 5 ha. Marginal and small farmers cannot afford the initial cost of T&T. Technical manpower and maintenance facilities for T&T are inadequate in DCs. In slushy and water-logged fields (e.g. parts of India, Bangladesh and Thailand), T&T is not suitable. In narrow-terraced fields and hilly regions (Nepal, Mexico and Bali islands), tractors cannot function. Most farmers in South Asia maintain cows and buffaloes for milk. Male calves readily become available as DAs. Thus, for all such situations, DAP becomes inevitable or appropriate.

Animal-drawn vehicles (ADVs) are suitable for rural areas under certain conditions, viz. uneven terrain, small loads, short distances and where time is not a critical factor. Since 50% of India's villages are not connected by roads, ADVs are the only mode of transport for goods and passengers. Also, in India, two-thirds of rural transport is hauled by 13 million ADVs. Asia, Africa and South America together account for 62% of land area, but have only 23% of surfaced roads. Africa and Latin America together have only 7% of the world's sur-

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faced roads. Seventy per cent of the world's population living in DCs have access only to 12% of the world's rail and 22% of road transport.

The situation in Southeast and South Asian countries as well as Burma, Indochina, China and Africa is the same as that in India. There is good scope for introducing ADVs in African countries. In rural areas, farmers already have DAs for ploughing and ADVs become a convenient adjunct equipment for intra and inter-village as well as village-urban transportation of goods and people. Most hospitals are urban-based, and ADVs are the only means of taking sick people for treatment.

Even in urban areas, ADVs are economically viable where: loads are less than 3t, distance is less than 30 km, loading and unloading time is high, compared to travel time, and number of collection points (garbage) or distribution points (milk, vegetable, water, oil) is large. For instance, India's 3 million urban-based traditional ADVs transport 20 billion tonnes of freight per year. Transport capability can be doubled when ADVs are improved. ASEAN countries have not fully exploited the potential of ADVs.

In Asian countries, ADIs and ADVs have become complementary, raising economic viability through increased employment and earnings. In India, rural-based DAs are used only for 100 days/year for ploughing and transportation. Since DAs are idle and non-productive for most parts of the year, they are kept on a maintenance diet, and not fed adequately. When the ploughing season begins, they are too weak to work. Unemployment and under-employment during off-season are major problems in most developing countries, particularly in Asia and Africa. Providing farmers and landless labourers with improved ADVs (either owned or rented) will enable them to use the DAs, during off-season, in nearby urban areas on a professional basis. Increased earnings enable farmers to feed animals well.

Lack of indigenous petroleum resources is another major problem faced by some Third World countries, particularly low-income countries for whom DAP becomes inevitable or appropriate.

Indonesia, Laos, Kampuchea, Vietnam, Philippines and Thailand are experiencing acute shortages of DAs. Some of these countries have banned slaughter of DAs in order to conserve DAP stock. The position of DAP in African countries is desperate—shortage or underutilisation of DAs in some countries, or no history of using DAP in others. In rural areas, women transport most of the goods as head load. Countries, such as Tanzania, Botswana, Ethiopia, Somalia, etc., have to upgrade their DAP. In others, considerable work is necessary to introduce DAP.

In countries where milk is part of the diet, DAs are a by-product of the milk system. Special effort is, therefore, required to rear DAs exclusively for draught. However, China, which does not use milk extensively, uses DAP in a big way. Indonesia uses female DAs for work. DAs provide organic manure. India's 200 million cattle provide 1 billion tons of wet dung per year. China has 10 million biogas plants converting dung into fuel and enriched manure. The fuel thus provided helps preserve valuable forest resources and scarce fuelwood in rural areas. Most developing countries, however, have not yet installed biogas plants on a large scale.

Slaughter and By-Products

Animals provide meat, skin, bone, horn, blood and many other by-products useful to pharmaceutical and other industries. In most Asian countries, animals are not reared for meat but for milk and draught purposes. In India, cattle and buffaloes alone make available 4 million tons of meat, and the animal system contributes 10% to India's gross national product. Developing countries should formulate judicious programs for rearing cattle and buffaloes in such a way that: (a) milk animals should be used for draught during their dry period only thereafter sent for slaughter; (b) male animals should be used for draught first, and only then sent for slaughter; (c) breeding programs should be aimed at producing milk-cum-draught cattle and buffaloes, rather than milk alone; and (d) animals should not be raised exclusively for slaughter.

DAs, ADIs and ADVs together form the main set of instruments of production for millions of marginal and small farmers, most of whom are poor. In rural areas, DAs are more equitably distributed than any other asset, and can be sold readily to raise money at times of emergency. In India, they are not mere economic entities but are part of tradition and culture.

Thus, from many points of view, DAP is an outstanding example of mass application of appropriate technology. DAP is complementary to petroleum-based power (PBP), without competing or conflicting with it. In fact, PBP could be encouraged, wherever it is technically feasible, economically viable and ecologically desirable. DAP need be retained and encouraged only where it is inevitable or appropriate. But, DAP should not be left to linger at the present level of low efficiency. In fact, improved DAP, which produces surplus earnings, will pave the way for transition to PBP.

Neglect and Consequences

Since DAP is in the unorganised sector, most developing countries tend to neglect it partly due to lack of appreciation of the rationale and partly because they have no effective institutions for upgrading it. Inefficiency of DAP systems has led to numerous adverse consequences: (a) millions depending on DAP live at a subsistence level, which tends to perpetuate poverty and privation; (b) the life span of DAs is reduced because of injuries to the neck, and partly because they work at peak capacity all the time; (c) draught capacity is wasted; (d) DAs suffer in many ways: inadequate feed and health care, ill-treatment and abuse, etc., all affecting their efficiency and reducing their capacity; (e) traditional ADVs damage roads; (f) impedes rural development and reduces agricultural output.

Improved ADIs and ADVs

Improved designs of ADIs have already been developed in Asia and Africa, but are not yet in use because of high cost and lack of promotion. CEEMAT in France and FAO have been helping African countries in popularising improved ADIs. China is already using improved designs. For semi-arid tropical regions, the International Centre for Research in the Semi-Arid Tropics (ICRISAT) at Hyderabad in India has evolved a multipurpose tool carrier. It has been found that the time and effort for ploughing can be reduced by 80% with improved ADIs.

There may be more than 25 million ADVs in the Third World. In India, only 1 million out of 15 million, and China's 5 million, have been modernised. There are no reliable statistics regarding the number of ADVs in other Asian and African countries. Major improvements include: lighter platform, smooth bearings, steel wheels, hard rubber or pneumatic tyres, brake, better harnessing device, etc. The capacity of a traditional large wooden-wheel ADV with iron tyres ranges up to 1t, while an improved ADV can haul 3t with reduced burden on the animal. China and some Asian countries have introduced smooth bearings, steel wheels and pneumatic tyres. South Asia is still far behind.

An improved cart may cost 50–100% more, but earnings could be three-fold. Also, for the same load, 1t, a single animal is adequate, instead of two used at present. Use of a single animal for ploughing and carting reduces capital and recurring cost. Other advantages are: (a) reduced burden on the animal, enabling longer working hours; (b) reduced fatigue and injury, and longer life span of the animals; (c) reduced damage to roads; and (d) increased transport capability and speed of movement. Even in India, which has an enormous investment in DAP, very little has been done to disseminate improved versions of ADIs and ADVs. The problem seems more acute in other Asian countries, where there is not even awareness of the importance of ADVs as complementary to ADIs.

Complementary use of ADIs and ADVs leads to higher employment and earnings, thus raising the economic viability of the DAP system. Countries such as the Philippines, Thailand, Indonesia, Burma and Indochina are compelled to use ADIs, but they are not using the potential of DAs for ADVs. Only China has attained a high degree of utilisation of DAs. Africa is still far behind Asian countries and therefore needs greater attention.

In Asia, the traditional yoke, made of rough rigid wood, is placed on the neck both for ploughing and carting. This yoke injures the animal's neck and reduces its draught capability. In some countries of Africa, the method of anchoring the yoke to the horns has been introduced. The best harnessing device is the 'even-bar system' for ploughing and 'double-piece yoke' for carting, where two or more animals of different species, sizes and strength can be hitched as in tandem. In the double yoke system, one yoke sits on the back of the animal carrying the vertical load, and the second yoke around the neck is used for hauling. This system eliminates neck injury, and also increases draught capability.

These two systems enable use of young DAs for ploughing and carting, making them productive and economical to keep. At present, in most cases, they are slaughtered as farmers are unable to rear them to working age (about 3 years). In India alone about 6 million male buffalo calves and 4 million male calves of crossbred cows are slaughtered soon after their birth, since there is no institutional arrangement to rear them to working age. Furthermore, cows and female buffaloes can be hitched to ploughs and carts during their dry period, or after the normal lactation period. Only China is using the even-bar and double-piece yoke system.

Other Draught Animals

There are 40 million donkeys in DCs, the potential use of which has not been fully exploited. With a special breeding system, China has raised 8 million high-bred donkeys for carting. Other countries use donkeys as pack animals with a capacity of only 50 kg, while donkey carts in China haul 400 kg. In Africa, most of the intra- and inter-village transport of goods is done by women as head load. As in China, part of this load can be transferred to donkeys—as pack animals or by hauling carts. Donkeys need much less attention than other DAs. Donkey carting is a major modernisation program that could be introduced in all DCs.

Male buffaloes are excellent draught animals, the potential of which has not been fully exploited. Buffaloes are well suited for ploughing in slushy and water-logged fields. In South China, male and female buffaloes are used for draught purposes. Like the program for cattle, there should be a similar combination of milk/draught, and slaughter. Though buffaloes are slower than bullocks, they can haul more weight. Buffaloes are also used for logging in Burma and Thailand.

Camels are used mostly as pack animals in Africa and in Mongolian China. In India, camel carts are popular, most of which are improved versions. Southeast and South Asia countries do not use horses and mules except for passenger transport in urban areas. China uses horses and mules for ploughing and carting. The possibility of extensive use of equines in Southeast and South Asia countries has to be investigated, since they are good for urban transportation. Elephants are used for logging in India and Burma. Yaks are used in mountainous regions. Donkeys and mules are the only means of transport in hilly regions, as pack animals.

DAs and Their Importance

An idea of the extent of dependence on DAP can be obtained from the distribution of population of DAs. However, most DCs do not collect or maintain reliable data on DAs and ADVs. FAO is now pressing member countries to maintain statistics on DAP. An estimate of the order of magnitude of DAs in a few countries is shown in Table 1. These countries have 350 million out of 400 million DAs, of which roughly 90% are in Asia.

FAO publishes data on animals used for milk, draught and slaughter together, and not separately for draught. Using these data, along with other indices, a rough estimate of DA population, by species, is given in Table 2. Buffaloes and cattle are 76%, 20% are equines, and 4% are camels.

Fragmentation of land is continuing, which means more dependence on DAP. DCs import 100 million tons of food grains per year, which may rise to 150 million tons by the year 2000. There is already an acute shortage of energy for cultivation, as much as 50%. Energy input may have to be doubled for optimal agricultural production, the bulk of which has to necessarily come from DAP.

Replacement of DAP

Output of DAs varies between 0.4 and 0.8 HP. Taking a figure of 0.5, power made available by 300 million DAs, at working age, may be of the order of 150 million HP. Though theoretically a tractor may be able to carry out work of 40 pairs of DAs, it is believed that one tractor can replace only five pairs of DAs in actual practice, because of the organisational constraints and widely dispersed nature of energy application.

Based on this practical consideration, replacement of DAP by PBP may need 30 million T&T, costing between $200 and $300 billion, plus $5 billion annually for petroleum fuel. DCs with meagre indigenous petroleum resources already have foreign exchange problems for development. While petroleum is inevitable for certain sectors and activities, DAP is an alternative in agriculture and small-scale transportation.

Table 1. Draught animal population in selected countries (all figures in millions).

	Cattle	Buffaloes	Horses	Mules	Donkeys	Camels
India (young only)	110.0	16.0	1.0	0.1	1.0	1.7
China (young only)	53.0	17.0	11.0	4.0	7.4	1.1 (Llamas)
Bangladesh	10.0	1.0	—	—	—	—
Thailand	3.0	5.0	—	—	—	—
Pakistan	7.0	0.5	0.5	0.1	2.3	0.8
Ethiopia	6.0	—	1.5	1.4	3.9	1.0
Indonesia	3.5	2.0	—	—	—	—
Burma	4.0	1.0	—	—	—	—
Nepal	2.8	2.0	—	—	—	—
Philippines	0.6	3.0	0.3	—	—	—
Mexico	2.8	—	6.5	3.2	3.2	—
Brazil	2.6	n.a.	2.0	1.7	1.7	—
Turkey	2.5	—	0.6	0.3	1.4	—
Colombia	1.3	—	1.0	0.6	0.6	—
Tanzania	1.0	—	—	—	0.2	—
Chile	0.3	—	0.5	—	—	—
Peru	0.1	—	0.4	0.2	0.5	1.2 (and Yaks)

Table 2. Draught animal population* by species (all figures in millions).

	Milk + Draught + Meat			Estimated DAs in DCs
	Total world	Developed all	Developing all	
Cattle & Yaks	1,212.0	425.0	787.0	246
Buffaloes	130.6	0.9	129.7	60
Horses	61.8	22.4	39.4	27
Mules	11.6	0.7	10.9	10
Donkeys	42.8	2.0	40.8	40
Camels	16.8	0.2	16.6	16
Llamas	1.4	—	1.4	1

* Yaks of China have been included under cattle; there may be about 20,000 elephants engaged in logging work.

FAO's estimate of the global share of manual labour, DAP and PBP, given in Table 3, shows that the energy for 52% of area cultivated in DCs is still provided by DAP. Though mechanisation may be rapid in South America and West Asia, according to FAO, the share of PBP in Asia and Africa would still be only 10% by the year 2000. In Africa, manual labour is still predominant. Even in India, 10 million marginal farmers have no DAs for ploughing. Therefore, one direction of modernisation ought to be upgrading manual labour to DAP.

Winrock International (1978) estimates of proportion of ML, DAP and PBP show: (a) percentage of DAP, as a proportion of DAP plus PBP, is very high: Africa 82; Far East (excluding China) 99; Near East (excluding India) 88; India 99; Argentina 54; France 24; USA 1; (b) in Philippines and Thailand, two ASEAN countries having major mechanisation programs, PBP is only 2% for holdings less than 5 ha; (c) predominance of ML and DAP in rice-producing countries of Asia, shows that, for holdings less than 4 ha, the number of agricultural workers varies between 0.7 and 2.5, and that ML constitutes 50%, DAP 40%, and PBP 10%.

Modernisation of DAP

It would be evident from the foregoing that dependence on DAP is inevitable, and that there is no conflict with PBP. Creating awareness regarding the massive contribution of DAP, and the urgent need to upgrade it, ought to be the first step in the modernisation program. For this purpose, studies, R&D, seminars and conferences should be organised in countries with high-level participation of leaders and government officials. Initiative from prestigious institutions and UN systems would help to bring credibility for such efforts.

DAP is closely linked with adjunct sectoral systems, such as milk, meat and slaughter by-products, biogas, environment, social forestry, rural industries, agriculture production, rural transportation and development, animal husbandry and veterinary services, cooperatives and credit, marketing and extension, etc. Some of these sectors, like slaughter, are totally neglected by the DCs. Integration and coordination and concurrent modernisation of adjunct systems would help to improve the technical and economic viability of DAP.

Economic evaluation of DAP vs tractor has often gone against DAP, since the analysis compared an inefficient DA with a modern tractor system assuming high utilisation. Also, contribution of tractors to incremental agriculture production in DCs has been exaggerated. Low consumption of energy per unit of output in DCs has not been recognised, while the high energy consumption in advanced

Table 3. Area cultivated—1975 (in million hectares).*

		Power Sources					
		Hand Labour		DAP		Tractors	
	Area	Area	%	Area	%	Area	%
Developing Countries	479	125	26	250	52	104	22
Developed Countries	644	44	7	63	11	537	82

* Excludes China, which cultivates 100 million ha with DAP and PBP.

countries is ignored. Therefore, economic evaluation has to be on a total systems basis, rather than segmented.

DAP is in the non-organised sector (NOS), where 80% of the total work force is employed in most DCs. Existing institutional models, particularly those of the governmental apparatus, have not been successful in delivering technology to and managing production in, the NOS. The NOS is undermanaged, or not managed at all, in most DCs. Development of model institutions and training of manpower are important prerequisites to upgrade activities in the NOS, particularly DAP.

Cooperatives for credit and marketing, cooperatives for private renting/hiring, etc., are possible solutions for DAP. But, DAP does not now have such infrastructure. When ADIs and ADVs are modernised, there will be sufficient financial incentives to attract small entrepreneurs to get into renting, breeding programs, manufacture of ADIs and ADVs, veterinary service, etc. At present, since profit margins are too small, entrepreneurs and the organised industry sector are not coming forward.

Government will have to come in by way of institutional support and subsidies, at least in the initial stages. Cost of such modernisation will be more than offset by the spectacular gains possible by modernising the DAP system. This is not recognised, however, since the present losses are not in the account books of government or private systems. Macro systems analysis and economic evaluation will help to arrive at the extent of effort and financial support that can be justified to modernise DAP and adjunct systems.

Technology for upgrading DAP is known. The problem is one of transfer of technology and practices amongst countries through regional cooperation, and within countries through massive extension. R&D institutions and extension agencies, already existing for other sectors and activities, should be given additional responsibility for DAP.

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Draught Animal Power Systems in Sub-Saharan Africa: Their Production Impact and Research Needs

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THE widespread failure of capital intensive mechanisation schemes in sub-Saharan Africa, combined with major shifts in the terms of trade between African countries and industrialised countries in favour of the latter, have caused many policymakers to review their agricultural mechanisation strategies. As a consequence, draught animal powered (DAP) mechanisation is again assuming some prominence and receiving development inputs both from the African countries and aid agencies.

The success of DAP systems as part of agricultural development strategy in sub-Saharan Africa will depend importantly upon socioeconomic factors. This paper provides an overview of the more important socioeconomic factors as they relate to the current utilisation of DAP agricultural systems and the influence of these factors on wider-spread adoption of such systems in African agriculture. There is an urgent need to have more productive and more stable farming systems in many zones of the continent. Properly researched and promoted DAP technologies can help achieve these goals.

Impact of DAP on Production

An estimated 15 million draught animals are in regular use in sub-Saharan Africa. Together these animals cultivate between 5 and 10% of the land area sown to annual crops (FAO, Production Yearbook 1983). While data are limited, all but a small percentage of draught animals are oxen, the remainder are equines (donkeys, horses and mules) and camels. Draught animals cultivate about 10 million ha/year. There are regional differences in the agricultural uses of draught animals, but their most important contribution is for cultivation and seeding. Overall their use for mid-season and postharvest operations such as weeding and threshing respectively are of lesser importance at this time. The use of donkeys as pack animals is extensive, e.g. in Ethiopia.

The largest draught animal population is in Ethiopia, with perhaps 50% of the total draught animals in sub-Saharan Africa. Ethiopia is also the only sub-Saharan country where it is an ancient tradition to use oxen (in pairs) for cultivation and unmechanised threshing. In all other countries where draught animals are now used, the practice was introduced, mainly in this century and in the context of cash crop production. Countries where DAP technologies are widely used in such crop production systems are Mali (for dryland cotton) and Senegal (for groundnuts).

Labour Use and Area Cultivated

DAP is reported to have four main effects on agricultural production. First, DAP systems are labour-saving per hectare as compared with hoe cultivation systems, the latter being the dominant mode of cultivation in sub-Saharan Africa. Insofar as DAP use in agricultural production *per se* is for land preparation and not for other phases of crop production, the labour-saving aspect of DAP allows land-rich agriculturalists to expand the area sown to crops. The extent to which this second effect is important in any farming system depends in turn upon supplies of family labour to weed their fields. All too often the labour-saving feature of DAP cultivation systems is not expressed because of the constraint on family labour for other field operations such as weeding. African farmers tend to limit the area of crops they sow to that which they can properly manage for all field operations.

The labour-saving attribute of DAP systems can allow improved timeliness of planting when it displaces manual operations. This is an important consideration for those farming systems where even a delay of one week in planting can cause signifi-

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cant yield reductions. However, DAP cultivation can hinder timeliness if it creates a new activity, such as in some parts of semi-arid Africa where seedbeds are not prepared and seed is normally placed in simple hoe holes made at planting time.

Crop Yields

The third, and disputed effect of using DAP systems instead of manual land preparation, is on yields per hectare. Available evidence suggests that yield gains of DAP systems over manual systems are at best modest. Reported increases are mainly from experiment station trials. Evidence from farmers' fields does not support the claims of proponents that DAP systems are substantially higher yielding than manual systems. In part this is explained by the fact that experiment station trials are usually on small plots rather than farm-scale fields. In the former case cultivation can be quickly followed by planting and timeliness is assured. In the latter case planting is somewhat delayed because the farmer has several plots to prepare and sow in sequence.

Crop Mix

The fourth effect of using DAP systems concerns the crop mix used by farmers. This effect is most pronounced on heavier soils supporting relatively high human population densities. In Ethiopia, for example, cereals and pulses have differential land preparation requirements. Farmers with an adequate supply of draught power have higher fractions of their farms sown to cereals than farmers owning less than a pair of oxen. Furthermore, those farmers owning at least a pair of oxen cultivate significantly larger land areas. Also cereal prices in Ethiopia are ordinarily higher than pulses, so the combined effects on area sown and crop mix allow farmers with adequate power to have much higher incomes than their neighbours with less draught power for cultivation.

Africa has many different agricultural systems and generalisations are difficult to make. However, from the studies available it may be concluded that the most important effects of DAP systems *vis à vis* manual systems are savings on labour inputs and on expansion of cropped areas.

Overview of DAP

Draught Oxen Breeds

The majority of draught oxen in Africa are of *Bos indicus* breeds. Taurine breeds are of limited importance and are used mainly in the fringes of areas subject to tsetse fly challenge. Tsetse flies are the vector for trypanosomiasis, a disease severely limiting the use in tsetse fly areas of *Bos indicus* breeds which are not tolerant to the disease.

The *Bos indicus* breeds used as draught animals in sub-Saharan Africa have liveweights when they are worked which seldom exceed 350 kg per head. In all cases oxen are worked principally after extended dry seasons of up to 200 days and are therefore generally in poor condition for work. Ethiopian farmers are often obliged to use mature oxen for cultivation with liveweights as low as 250 kg per head when those same animals weigh over 350 kg when in good condition. The requirement to sow crops in a timely way in most African farming systems obliges farmers to use weakened animals. Traditional zero tillage systems may not be displaced by DAP methods if the latter causes significant delays in planting.

Oxen Supplies

Farming systems using DAP technologies in eastern Africa and West Africa are different in at least one important aspect. In eastern Africa, farmers using draught oxen are largely dependent upon their own farming areas for the supply of replacement oxen. They have only limited access to surplus male stock from pastoralist areas. This within-system dependence obliges those agricultural systems to support both parent and replacement stock, thereby increasing the gross feed demands of the draught animal component on the farming system.

This is in strong contrast to West Africa where large-scale pastoralist areas bordering on the settled agricultural zones are the major sources of working oxen. Farmers in these West African agricultural areas have therefore to purchase their oxen. Credit systems for oxen purchase are non-existent, so oxen sales provide a major income source for pastoralists adjacent to these farming areas. While such payments are a burden on West African farmers compared to their counterparts in eastern Africa, West African farmers keep fewer stock overall and are therefore relatively better able to provide a proper level of feeding for their stock. Agricultural systems using DAP are areas of relatively high and usually rapidly increasing population densities. For these reasons it is more likely that West rather than East African agricultural systems using DAP will be able to maintain current levels of ownership of draught animals per farm without confronting major shortfalls in feed supplies for their stock.

Working Regimes and Feed Supplies

How different are the systems of utilisation of draught animals across sub-Saharan Africa? In the more temperate areas (< 30 °C), draught oxen are typically used for some 6–8 hours/day during the cultivation season. In the semi-arid tropics the work period is from 4–6 hours/day, with the reduced time originating because of greater nutritional stress in the latter areas and temperature stress on the animals worked in ambient temperatures often exceeding 40 °C.

Differences in working regimes do occur even with adjacent and nominally similar agricultural systems. In Ethiopia, for example, farmers in some highland farming areas work their draught animals in two periods per day and the animals are fed and watered in the work break, while farmers in adjacent areas work their animals for the same total time per day without such a break. The origins of the different practices are not known. While theory suggests that the break will add to daily work output, field data show no significant differences in areas cultivated per day between the two systems of oxen use. In ILCA field studies, reported in Gryseels and Anderson (1983), oxen are worked in the Ethiopian highlands for some 450 pair hours/year, equivalent to some 50–70 days/year. For the remainder of the year these animals are little used in support of agriculture, except after harvest for threshing in the traditional manner by trampling.

Insofar as DAP technologies are for the most part used in mixed dryland farming systems, and are most important in agricultural systems where agricultural land is becoming increasingly limiting, the feed resources available to oxen and attendant stock are becoming progressively more limiting. To an extent the cultivation of human food crops increases the total availability of livestock feeds but the feeding values of these residues are typically less than the native pastures which these crops replace. Farmers in such situations favour their work oxen over other classes of livestock in regard to the use of usually limited amounts of high quality feedstuffs. As a consequence, the reproductive performance and growth rates of cows and replacement stock respectively are impaired. This trend is becoming evident in several of the more intensively farmed farming systems in eastern Africa, as for example in southern Zimbabwe and many parts of the Ethiopian highlands. The problem will become progressively more acute as farm sizes diminish and per animal feed resources become even more limited. Feed quality and quantity will both be of concern in the coming years.

Implements, Credit and Technology Adoption

It has been noted that DAP systems in West Africa were introduced mainly in the context of cash cropping programs. Thus far, the use of DAP systems in that zone are still mainly for such crops and uptake by farmers not involved in cash crop production has been limited. A partial explanation of this limited voluntary uptake by the latter groups is their limited access to credit for the purchase of draught implements. The West African agricultural zones are currently land rich. Ordinarily land is not owned with specific titles over plots held by individual farmers. In such cases, subsistence smallholders have limited opportunities to secure credit with repayment periods extending over several years.

An additional reason for limited adoption of DAP by farmers growing traditional crops is that the available draught animal implements are mainly ploughs and seeders. This equipment range is adequate, but still less than ideal, for cash cropping systems where farmers can afford to apply herbicides or hire labour for weeding. When larger areas are cultivated there is a proportional increase in weeding labour required. Labour for this activity is already one of the most important constraints on food crop production in West Africa, as indeed it is in most sub-Saharan farming systems.

Assuming that research will result in the development of appropriate mechanised weeders, the technology will not flow rapidly to farmers growing traditional crops unless the DAP package is promoted and supported by credit systems for these farmers. In the short run the weeder would be of immediate interest to cash croppers with access to credit through cash crop marketing organisations. However, traditional farmers cannot offer the land they till as collateral for loans for equipment purchase. Insofar as these smallholders are the main groups in rural communities most at risk in times of crop failure, they would benefit substantially from technology development such as mechanised weeders and access to credit to enable them to pursue a land expansion strategy.

DAP Research Needs

Communication and Organisation

Over the past 40 years researchers in both Anglophone and Francophone countries have designed and tested many hundreds of implements to be used with draught animals. Most of the designs have never been produced commercially. Furthermore, most of the design and testing resources have gone into work on ploughs, seeders and carts.

Inevitably, because of the historically limited exchange of information between Anglophone and Francophone researchers and developers, there has been considerable duplication of effort. Also, there has been limited transfer of favourable findings from one group to the other. The language barrier has also proven to be a trade barrier, with very limited sales of implements and equipment between the countries concerned. In part the barrier is being eroded as intercountry trade expands and as bilateral and multilateral research and development agencies increase the exposure of African researchers and developers to developments in DAP systems. Increased collaboration between all researchers and developers concerned will provide positive stimulus to expanded DAP utilisation in sub-Saharan Africa.

While the allocation of research funds into DAP systems in the last several decades cannot be determined, it is evident from the professional literature that the majority of the effort has gone into implement design, testing and production. As a consequence soil preparation methods are now well established for most of the important agricultural systems where DAP technologies are used.

Tradition is a strong factor mitigating against adoption of new technologies and variants of current practice. However, changes to existing practice to reduce the DAP input to crop production, without prejudicing crop yields, is a priority research area. Appreciation of the social and economic factors influencing both current practice and the adoption of new systems will be central to effecting such changes. Multidisciplinary DAP research teams will be more appropriate than the singular engineering approach taken in the past.

Uses of Draught Animals

Multipurpose use of draught animals will evolve in most existing DAP systems. The basic effects of such changes will be to extend the period each year when the animals can contribute to farm production. The technical efficiency of work performance based upon, for instance, calculations of energy input and work output for the time work is performed overstates the efficiencies in a total resource use sense as oxen and attendant stock must be fed for 365 days each year. The economic cost of providing for the full year is much greater than the cost of the actual work period. If additional productive tasks can be performed by draught animals at relatively small marginal cost in terms of extra feed and labour inputs, then the relative costs of performing conventional duties by draught animals will be reduced and overall productivity gains at the farm level will be achieved. Some examples of multipurpose use of draught animals are discussed in the following paragraphs.

In Ethiopia, as in several countries, oxen are not used as transport animals. Donkeys perform this role as pack animals and donkey carts are virtually non-existent. If agricultural development proceeds in the country then the quantities of purchased inputs and products from farmers will increase, in turn increasing the demand for agricultural transport. For this reason it is likely in Ethiopia that oxen carts will develop and become an integral part of farm operations. Using oxen as transport animals with carts is a relatively undemanding work task but does require substantial capital investment. Credit systems will be necessary to support such a change to current practice.

Smallholder dairy development is a priority in many African countries. The crossbred cows on which such enterprises are typically based require generally higher quality feed than currently available to achieve production levels of 1500–2000 l/cow/year under farm conditions. To the extent that dairy development projects are usually in areas where cattle are already kept, often as draught animals, the introduction of the crossbred cow will tend to reduce the feed supplies available to traditional stock. This is especially the case if crossbred cows are kept by smallholders without special purpose fodders being produced for the cows. If cows can be used both as draught animals and as milk producers, this would substantially reduce the requirement to keep traditional stock to provide draught power.

At this time cows are used as draught animals in Africa to a limited extent only, and most commonly by farmers without sufficient oxen available at the time field cultivation must be done. Only indigenous breeds are used in significant numbers. As milk yields and milk offtakes and reproductive performances of the majority of indigenous breeds are significantly lower than breeds of temperate origins, the production penalties arising from the use of cows are minimal. Despite this, there is reported and observable reluctance to the routine use of cows as draught animals. This reluctance may mitigate against the adoption of the routine joint use of crossbred cows as draught animals and as milk producers. Important technical research questions arise in regard to such joint use. For example, at different levels of nutrition, what are the tradeoffs among milk production, reproduction rates and work output. Satisfactory resolution of such questions will support the development of this draught cow option, but adoption will follow only if the social and economic contexts in which the technology is promoted are appropriate. Limited research results are available on this topic. ILCA has initiated such a study in Ethiopia but genotype-environment interactions will be important for this new technology, necessitating such work to be replicated at several locations over the coming years.

Nutrition of Draught Animals

Relatively little research has been done on the nutritional needs of working animals. That which has been done or is in progress is almost exclusively with oxen. The history of DAP development in Europe in the last few centuries suggests strongly that there are substantial and as yet unexploited opportunities to use other stock such as horses, donkeys, and mules as well as cows. In Europe, specialist breeds of draught animals were developed for different agricultural systems. There is good reason to expect that a measure of the same type of specialisation may occur in sub-Saharan Africa. Donkeys, for example, of which sub-Saharan Africa has well over 7 million, could be a useful target for use as draught animals in minimum draught power cultivation systems. To date researchers have given little attention to this species as a draught animal.

At this time, and in eastern Africa especially, smallholders' livestock are heavily dependent upon crop by-products for maintenance and production. Human population densities are also increasing rapidly in the sub-humid zone of West Africa, so in that area too livestock will become more dependent upon crop residues for their nutrition. Applied nutritional research is needed to improve the utilisation of these materials by working oxen and other classes of cattle. Fodder legumes and strategic use of purchased inputs such as agroindustrial by-products and other products such as urea will most likely enable this nutritional deficit to be overcome. Improved crop by-product-based feeding systems will therefore be of paramount importance for all DAP farming systems in the coming years.

As farm sizes diminish in sub-Saharan Africa, the real needs for draught power, as opposed to perceived needs based on tradition and current practice by farmers, are reduced. In many cases more power is used for land preparation than is necessary. Minimum power cultivation systems are needed urgently in many areas. Their development is a priority. When such systems are adopted they will also contribute importantly to resolution of the conflict which now occurs between the need to keep attendant stock to produce replacement oxen and the need to keep oxen for work. As many current cultivation systems are derivatives of systems developed in temperate agricultural areas, the special problems relating to the proper and sustained use of tropical soils warrant particular consideration. Minimum tillage systems for most of sub-Saharan Africa will also help address the particular problem of soil water conservation, a prerequisite to improved crop yields in agricultural areas of relatively low rainfall and short growing seasons.

Engineering Aspects

The considerable research and development inputs to the engineering experts of DAP in sub-Saharan Africa have already been highlighted. With proper assembly and dissemination of available data on the implements now in use, it can be argued that the major shortfalls in equipment needs are weeding tools and animal-powered threshers. Effective, low-cost mechanised weeders and threshers are not yet as available as they should be. Until such time as weeding operations can be mechanised, ploughs and seeders alone will not have the total impact on the adoption of DAP packages or on food production, both of which are necessary to feed the burgeoning populations of most African countries.

DAP technologies are complex and concern more than engineering considerations. As such the process of problem identification, research, extension and adoption will be made more efficient if a multidisciplinary approach to problem-solving is adopted. The farming systems approach to research—more recently called 'on-farm research with a farming systems perspective' (Simmonds 1984)—is an appropriate approach to publicly supported research in DAP systems. By adopting this approach the biases in station research and disappointments arising through non-adoption by farmers of improved technologies tested only under station conditions will be reduced. Concerns about the relevance to farm conditions of station-based DAP research can be illustrated by the following examples.

The Case For On-Farm Research

African farmers, as already noted, are usually obliged to use animals which are in poor working condition. In some instances oxen are worked at the end of the dry season at liveweights up to 20% below peak weight at the end of the main crop season. By contrast, research station animals are, with rare exception, kept in 'ideal' working condition. It is no great surprise then that farmers find their oxen are unable to use effectively the implements designed and tested to be used by well-nourished animals. Another departure from farm conditions which can negate the relevance of station research is the understandable reluctance of researchers to have weed-ridden fields. They overcome this by hiring labour as needed, which cannot be done by farmers able to draw only on family labour resources. Improper conclusions would then be drawn from the results of such station trials.

Thus, for several reasons 'realistic' DAP research is difficult to undertake under research station conditions. While on-farm trials are more demanding to design and implement and the researchers involved must, often reluctantly, accept less statistical rigour in the results produced, the greater relevance of the results so obtained will ultimately favour this orientation. A shift towards on-farm research does not deny the need and importance of station-based research. On-farm trials will be the best testing site for whole systems. Research station facilities will be best used for tests of components of these whole systems.

Original development of DAP came principally through public investments in research extension and credit systems. In recent years there are some important instances of 'new' technologies originating in the private sector. To the extent that this has occurred, as for example in central Mali where a small number of farmers are using an oxen-drawn weeder made by local blacksmiths, it provides evidence that in those areas there is sufficient confidence and skill in operating the basic DAP technology that innovation can occur.

More such spontaneous developments in response to problems will occur. The most important zone where the spontaneous adoption of DAP technology can be anticipated is the sub-humid zone of West Africa. In this zone, vitally important to West Africa's future food production, increasing numbers of settlers are moving in from the drought-ravaged areas to the north. Their presence is contributing to a systematic reduction in the tsetse fly population in the sub-humid zone. The area being sown to food crops is rapidly increasing as is the resident cattle population. It is currently a land-rich zone. Together these factors favour the rapid uptake of DAP farming systems.

Much improved collaboration among African researchers and developers concerned with DAP systems will be a prerequisite to enabling DAP technologies to support agricultural production to the extent which is needed. Many independent and disparate agencies are currently involved with these technologies, often with inadequate knowledge of the systems toward which they are targeting their work. Research and development networks having DAP issues as their principal focus will hasten and make such collaboration more effective. Some intiatives in this direction have already begun and need strengthening.

Summary

DAP systems already contribute importantly to food production in sub-Saharan Africa. The potential exists for them to make a significantly greater contribution. The research resources allocated to DAP on the issues outlined here and on other topics will need to be increased substantially in the coming years. However, technical knowledge alone will not be sufficient to favour adoption of findings by farmers. These technologies will usually need to be tailored to local circumstances, that is to farming systems. In this regard proper attention to the problems and constraints of these systems will be critical. Research station work will need to be matched closely to the needs of the target areas where the technologies are to be delivered. The multidisciplinary, farming systems approach to research will be the proper research orientation, as it takes due account of the social and economic circumstances of the target groups of farmers for whom research must be targeted if it is to be relevant in times when cost-effective research is vital.

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Research on Chinese Yellow Cattle Used for Draught in the People's Republic of China

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YELLOW cattle in China probably evolved from original Asiatic cattle that appeared during the Neolithic period, although some experts feel they may have evolved from wild cattle in Java and the Brahmin Archipelago, the original breed of Indian Zebu. There are a number of breeds of Chinese yellow cattle, such as Qionglei, Qin-chuan and Nan-yang, and Jin-nan cattle which all have a blood relationship with Zebu.

In 1983 the total number of large farm animals in China was approximately 103 million, 2.3% more than in 1982. Of this number, over 61 million were draught animals, 58 million were yellow cattle, over 19 million were water buffalo, and approximately 1 million were improved breeds and dairy cattle.

Indigenous yellow cattle are distributed throughout China. The cattle can be divided into three main regional types, based on distribution and consisting of a number of breeds: (1) northern type, including Mongolian cattle in Inner Mongolia, the northeast, north and northwest part of China: Yanbian breed is found mainly in Jilin, Liaoning and Heilongjiang provinces, the Fuzhou breed in Liaoning province; and Kazakh cattle in Xinjiang; (2) central China type, mainly including Qin-chuan breed, Nan-yang breed, Lu-xi breed and Jin-nan breed; and (3) southern type, including Qionglei breed, Min-nan breed, Sanjiang and Deng-chuan breeds, distributed in southern areas of China.

The five main improved yellow cattle breeds in China are the Qin-chuan, Nan-yang, Lu-xi, Yanbian, and Jin-nan. In 1983, the total number of the five breeds in the main producing areas was approximately 2 million, an increase of 7.9% over 1981.

The body weight and measurements of these breeds are summarised in Table 1. The yellow cattle breeds developed under different ecological and socioeconomic conditions.

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The main production areas of the Qin-chuan and Nan-yang breeds have a moist climate (annual rainfall 500–1200 mm), mild temperature (yearly average 12–15.5 °C), fertile soil and well-developed agriculture at altitudes up to 2400 m (mainly wheat, corn, sweet potato, bean and soybean). The Lu-xi breed is mainly distributed in the southwest part of Shandong province where the bean and other protein feedstuff supply is rich. In the Jin-nan Basin, where the Jin-nan breed originated, there is a temperate continental climate and well-developed agriculture. This area is called the granary of Shanxi province. The Yan-bian breed evolved through long periods of interbreeding and selection between Korean cattle and local breeds.

Large and strong draught animals are needed for intensive cultivation in agricultural areas. Breeders usually select large and strong cattle with good uniformity as breeder cattle, and emphasise selection and breeding for colour uniformity.

There has also been work done on cattle management, including feeding experiments, fine processing of coarse feeds, intensive feeding in busy seasons, etc.

Importance in Agriculture

Draught animals have a long history in China. The top draughting ability of the five breeds has been estimated as follows: male 275–475 kg; female 216–281 kg; bullock 289–348 kg, ranging from 55 to 77% of body weight; ploughing speed 0.03–0.08 ha/hour; draughting speed 0.9–1.2 m/sec.

Generally speaking, the draught ability of yellow cattle is in direct proportion to body weight. The four improved yellow cattle breeds in central China (Qin-chuan, Nan-Yang, Lu-xi, and Jin-nan) have excellent draught ability and the northern yellow breeds are noted for their strength, adaptability to heavy draught, tolerance to cold weather, and resistance to disease.

The southern breeds are usually fine boned, with a top draughting ability of up to 80–90% of body

Table 1. Body weight and measurements of some improved local yellow cattle breeds

Breed	Sex	No. head	Measurements (cm) Height	Length	Girth	CW	Weight	Year
Qin-chuan	M	125	141.5 ± 6.3	160.5 ± 11.2	200.5 ± 13.8	22.4 ± 1.3	594.5 ± 116.7	1981
	F	1051	124.5 ± 6.0	140.4 ± 9.6	170.8 ± 11.7	16.8 ± 1.3	381.3 ± 72.1	
Nan-yang	M	26	144.9 ± 9.5	159.8 ± 12.0	199.5 ± 21.1	20.4 ± 1.8	647.9 ± 176.3	1982
	F	223	126.3 ± 7.1	139.4 ± 10.3	169.2 ± 11.0	16.7 ± 1.1	411.8 ± 84.4	
Lu-xi	M	44	146.3 ± 6.9	160.9 ± 6.9	206.4 ± 13.2	20.97 ± 1.4	644.4 ± 108.5	1980
	F	157	123.6 ± 5.6	138.2 ± 8.9	168.0 ± 10.2	16.2 ± 1.1	365.6 ± 62.2	
Yan-bian	M	282	130.6 ± 4.4	151.8 ± 6.2	186.7 ± 7.1	19.9 ± 1.2	465.5 ± 61.8	1981
	F	268	121.8 ± 4.4	141.2 ± 5.3	171.9 ± 6.8	16.9 ± 0.98	365.2 ± 44.4	
Jin-nan	M	9	138.7	157.4	206.3	20.2	607.4	1979
	F	551	117.4	135.2	164.6	15.6	339.4	
Mean	M	—	140.4	158.08	199.88	20.77	591.44	—
	F	—	122.95	138.88	168.8	16.44	372.68	

weight, and are well adapted to mountainous regions. The milk-producing ability of Chinese yellow cattle breeds is limited. For example, the milk production of the Deng-chuan, bred mainly for milk, is only 838 kg in a 300-day lactation period (fat content of 5.58%). In 1980 agricultural crops in China covered about 14.5 million ha, of which 4.1 million were ploughed by machine. The rest was ploughed using draught animal power. In 1980, there were approximately 5 million draught animals in China so each animal had to work approximately 2 ha. In some areas, such as Shen-qui county in He-nan province, each animal is required to work 0.3 ha.

From 1949 to 1956 the population of yellow cattle increased from 35 to 54 million. However, the production of draught animals decreased to 44 million by 1961, but has been on the increase since 1979. The average draught animal population is now 0.57 head per family. In Zhoukou district, Henan province, the figure is 0.75.

Draught animals are well adapted to ploughing in mountainous areas and can make full use of the large areas of grassy hills for grazing. There are 286 million ha of natural grassland in China, accounting for about 30% of the territory. The usable grassland amounts to about 78%. The draught animal can also use agricultural by-products, converting two-thirds of agricultural products which cannot be used by people into draught power, manure, leather and meat.

The full development of draught animals is an important step in the strategy of agricultural economic development in China. The development of the draught animal is being encouraged. For example, the price of draught animals in Shanxi province has increased from 400 yuan to over 1000 yuan. However, people are not satisfied with the yellow cattle being used only for draught, since the draught season is only about 2 months/year. The small farm machine adapted to non-intensive land is being welcomed.

With the improving living standard of the Chinese people the demand for milk and meat is increasing rapidly. The farmers want the draught animal, previously used for production, to be used for meat and other products. There is, therefore, great potential for a triple-purpose breed: draught, milk and meat. The main markets for these products are the medium and large cities.

Chinese scientists have made great progress in breeding to improve the yellow cattle breed. Emphasis has been on improving the inferior characteristics including poor rump, poor muscle in thigh, late maturation, slow growth, and low milk production. Black and white dairy cattle have been used to improve the local breeds to increase milk production. China is also planning to develop meat/draught or milk/meat dual-purpose breeds of its own.

Conclusions

Yellow cattle will continue to play an important role in Chinese agriculture in the years ahead.

Chinese yellow cattle can produce high-quality beef. For example, using standard feed and routine management practices the average daily gain of Qin-chuan cattle breed, at the age of 18 months, was 0.7 kg in males, 0.55 kg in females, and 0.59 kg in bullocks. The dressing percentage was 58.25 and the net meat 50.8; the proportion of bone and meat was 1:6.1 and the eye-muscle area 97.02 cm^2. The meat was tender and welcomed by consumers.

In recent years the dairy cattle industry has been developing rapidly but the number of purebred Black and White is limited. With the large population of yellow cattle, and with emphasis on milk/draught dual-purpose animals, China's dairy cattle industry will have great potential for development and good progress has already been made in this area.

There are no special beef cattle breeds in China, and the old and disabled cattle are usually slaughtered for food. Since 1949 China has introduced 16 beef cattle breeds including dual-purpose breeds (Shorthorn, Limousin, etc.) from other countries. Besides intermating they have been used for improving the native yellow cattle. At the present time there are about 2.6 million improved beef cattle and dual-purpose cattle in China.

In Inner Mongolia, the Limousin bulls are used to improve the Mongolian hybrid cattle. The body weight of the F_1 bull at 13 months can reach 407 kg with a daily average weight gain of 1429 g in 82 days of feedlot fattening, dressing at 57% with net meat of 47% per head.

The draught performance of these crossbred animals is significantly higher than that of native breeds according to preliminary test results in Inner Mongolia.

Physiology of Work

Conflicting Requirements of Exercise and Heat Stress for Blood Flow Distribution in Domestic Animals

A. W. Bell* and J. R. S. Hales**

THE combined effects of exercise and heat stress on the human circulatory system have recently been reviewed (Brengelmann 1983; Nadel 1983; Rowell 1983). The essential physiological problems are not only the fact that the cardiovascular system must serve thermoregulatory requirements while maintaining its own integrity, but there is a 'conflict of interest' created by major increases in requirements for blood flow in both skeletal muscle and skin (Rowell 1977). Thus, contracting muscle requires increased blood flow to support an adequate level of aerobic metabolism, while increased skin blood flow is necessary to dissipate the markedly increased metabolic heat load imposed by exercise and prevent an intolerable rise in body temperature. This competition for blood flow intensifies if either the level of work increases or if high ambient temperatures and/or humidity impair the capacity to lose heat. An extension to such competition might be anticipated for the pregnant and post-prandial states.

The physiological effects of combined heat stress and exercise on draught animals have received little attention. Therefore, this review is particularly addressed to observations on small ruminants (sheep and goats) and non-ruminants (pigs and dogs).

Effects of Exercise

General Aspects

Central cardiovascular adjustments during human exercise, and influences of the type of exercise, training, age, sex, etc., are well documented (see Rowell 1974; Saltin and Rowell 1980). In brief, cardiac output (CO) is directly related to level of exercise and thus, whole-body oxygen consumption ($\dot{V}o_2$). However, the relation is curvilinear rather than linear because although heart rate tends to increase with $\dot{V}o_2$, cardiac stroke volume plateaus at relatively low levels of $\dot{V}o_2$, and may even decrease during very severe exercise. This general pattern of cardiovascular responses appears to be qualitatively similar in the dog (Barger et al. 1956; Wagner et al. 1977) and horse (Engelhardt 1977; Thomas and Fregin 1981), the only other species of large animals in which physiological and metabolic responses to graded exercise have been systematically studied.

Distribution of Cardiac Output

The major features of the redistribution of CO which occurs during exercise in humans are: increased % CO to working sekeletal muscle, in proportion to exercise intensity; substantially decreased % CO to the splanchnic region and kidneys, also proportional to the severity of exercise; and decreased % CO to some other non-exercising regions, particularly torso skin and resting skeletal muscle (Rowell 1974; 1983).

These observations probably present a reasonably correct qualitative picture of exercise-induced changes in blood flow distribution in humans, but accurate quantitation remains a problem. In recent studies on other species, this problem has been largely overcome by the use of radioactive microspheres.

WORKING MUSCLE

Data from exercising dogs (Fixler et al. 1976; Pannier and Leusen 1977), pigs (Sanders et al. 1976a), horses (Parks and Manohar 1983) and sheep (Bell et al. 1983) support the accepted concept of blood flow to working muscle increasing according to its metabolic requirements and thus, level of exercise. Responses in different groups of muscles have been compared and we have estimated that in sheep doing 'moderate-to-severe' treadmill exercise (3.3 to 5.9 fold increases in $\dot{V}o_2$ for 30 min), half the entire CO perfused muscles responsible for locomotion (Fig. 1). The degree to which

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blood flow to individual muscles increased over resting values varied from 3.6 fold (gastrocnemius) to 13 fold (biceps femoris).

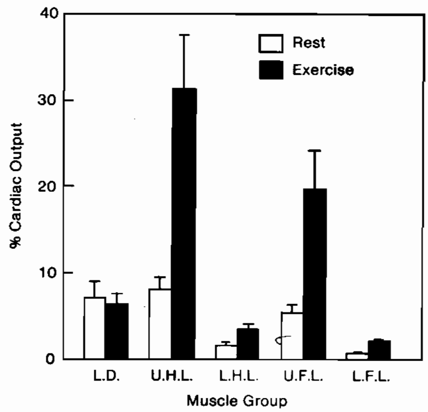

Fig. 1. Effect of exercise on distribution of cardiac output received by different groups of non-respiratory muscles (means ± SE for 5 sheep). LD, longissimus dorsi; UHL, upper hindlimb; LHL, lower hindlimb; UFL, upper forelimb; LFL, lower forelimb.

ABDOMINAL VISCERA

Despite recognised methodological limitations, it seems well established that in exercising humans, blood flow to the splanchnic tissues and kidneys is decreased in proportion to the severity of the exercise (Rowell 1974). This regional vasoconstriction is necessary to make sufficient blood volume available for the vasodilator responses in other regions, however, its role in ensuring adequate flow to contracting muscles varies considerably in different species.

In the dog, absolute levels of blood flow to the kidneys and splanchnic organs are relatively unaffected, even during exhaustive exercise (Sanders et al. 1976b). On the other hand, decreases in renal blood flow have been reported for the exercising pig (Sanders et al. 1976a), and in splanchnic blood flows in exercising sheep (Bell et al. 1983). It has been argued that $\dot{V}o_2$ max in the dog is limited more by the metabolic capacity of skeletal muscle than by CO, and that the cardiac reserve is normally large enough to meet the vasodilator requirements without any pronounced redistribution of CO (Saltin and Rowell 1980). Thus, when CO was experimentally restricted in exercising dogs, the redistribution of CO from non-exercising organs resembled that seen in other species (Higgens et al. 1972). A comparable situation arises in the heat-stressed dog (Hales and Dampney 1975) when, in contrast to other species, thermoregulatory needs are met by increasing CO, with little change in its distribution. $\dot{V}o_2$ max of the dog is considerably greater than that of most other species in which effects of exercise on blood flow distribution have been measured. In another highly athletic species, the horse, renal blood flow was unaltered during moderate exercise, but decreased to 20% of resting values during very severe exercise (13 times resting $\dot{V}o_2$; Parks and Manohar 1983).

SKIN

Cutaneous blood-flow responses to exercise are more complex than those of other organs, presumably because skin blood flow is affected both by thermal inputs (principally deep body core temperature (Tc), modulated by skin temperature (Tsk)) and non-thermal sympathetic nervous activity (Nadel 1980; Brengelmann 1983). Absolute levels may increase during exercise in a cool or thermoneutral environment, compared with resting values, because of the effect of increased metabolic heat production on Tc.

In sheep which were at or near maximal cutaneous vasoconstriction when resting, absolute torso skin blood flow decreased significantly during exercise but was increased 7.6, 2.1 and 2.8 times in the ears, forelimb and hindlimb, respectively (Table 1). Total skin blood flow was estimated to have decreased from 169 to 136 ml/min; this represented a decrease in % CO to total skin from 5.5 to 1.9% during exercise.

OTHER TISSUES

During severe exercise, non-exercising muscles may vasoconstrict in humans (Rowell 1974), but the quantitative significance of this in terms of providing blood volume is not clear. In dogs (Sanders et al. 1976b) and sheep (Hales et al. 1984) the fraction of CO distributed to the back muscles was more or less unchanged by exercise (Fig. 1); thus blood flow to these muscles increased during walking exercise, but to a much smaller degree than in the leg muscles directly involved in locomotion.

In exercising sheep, whole-body adipose tissue received about 15% of CO during both rest and exercise, despite a 1.6–3.1-fold increase in CO during exercise (Hales et al. 1984; Fig. 2). Therefore absolute blood flow increased, which is consistent with the marked increase in adipose tissue lipolysis and fatty acid mobilisation in exercising sheep (Pethick 1982).

The increased cardiorespiratory effort required to meet increased metabolic requirements during exercise is accompanied by increases in blood flow to the respiratory muscles and myocardium approxi-

Table 1. Effect of exercise on skin blood flow in sheep (means ± SE; n = 5).

Skin site	Blood flow (ml/100 g/min) Rest	Exercise	Blood flow (% CO) Rest	Exercise
Torso			5.3 ± 1.0	1.7 ± 0.2
Shoulder	8.7 ± 1.4	6.7 ± 1.1		
Midside	10.0 ± 1.4	7.6 ± 1.3		
Rump	13.4 ± 2.5	10.4 ± 1.0		
Extremities			0.17 ± 0.5	0.20 ± 0.06
Ears	0.82 ± 0.1	6.2 ± 2.6		
Forelimbs	1.9 ± 0.5	4.0 ± 1.3		
Hindlimbs	1.8 ± 0.4	5.7 ± 1.5		

mately in proportion to the severity of exercise.

ARTERIOVENOUS ANASTOMOSES

We have observed up to a 5-fold increase in perfusion of arteriovenous anastomoses (AVA) of the hind limb in exercising sheep (Hales et al. 1984), which presumably is a specific response to the increased requirement for heat loss.

Effects of Heat Stress

General Aspects

Reviews of overall cardiovascular responses to heat stress in domestic animals (Hales 1974; Whittow 1976) indicate considerable species variation in the magnitude of change in CO. In cattle (Whittow 1965) and dogs (Table 2; Hales and Dampney 1975), as in humans (Rowell 1974), CO tends to increase as Tc rises. In contrast, even severe hyperthermia (>2 °C increase in Tc) has little effect on CO in sheep (Table 2; Hales 1973a) or baboons (Hales et al. 1979). Both of the major evaporative heat loss effector mechanisms, sweating and panting, require increased blood flow. Of the species discussed below in relation to detailed changes in blood flow distribution, both man and baboon rely almost exclusively on evaporative and non-evaporative heat loss from the skin, whereas the dog and sheep rely principally on evaporative heat loss from the upper respiratory passages.

Table 2. Effect of severe heat stress on cardiac output and its distribution to respiratory and non-respiratory skeletal muscles in sheep and dogs.*

	Sheep TN	Sheep RSP	Sheep SDP	Dog RN	Dog RSP	Dog SDP
CO (l/min)	3.18	3.52	3.41	4.92	6.93	8.57
Resp. muscles (% CO)	2	14	15	3	11	17
Non-resp. muscles** (% CO)	12	9	23	42	38	31

* TN, thermoneutral environment; RSP, peak of rapid shallow panting, Tc raised ∿1 °C; SDP, slow deeper panting, Tc raised ∿2.5 °C.

** Estimated from values for representative samples from major muscle groups.

Distribution of Cardiac Output

In heat-stressed humans, a major increase in skin blood flow, which may exceed 4 l/min, is made possible by increased CO and redistribution of blood flow away from skeletal muscle, kidneys and the splanchnic region (Rowell 1983). A qualitatively similar picture for other animals has been briefly reviewed (Hales 1979; Rübsamen and Hales 1984).

SKIN

The significance of heat-induced changes in skin blood flow depends to a significant extent on the importance of sweating as an avenue for heat loss. In humans, sweating is overwhelmingly important as a thermoregulatory effector mechanism. The onset and rate of increase of both sweating and cutaneous vasodilation are related to Tsk and Tc (Wyss et al. 1974), although non-thermal factors such as exercise and posture can considerably modify the responses of skin blood flow to thermal inputs (Johnson and Park 1981; see below).

The effect of heat stress on whole-body cutaneous blood flow was very much smaller in sheep (Hales 1973a) and dogs (Hales and Dampney 1975) than in humans. Both these species pant to lose heat and show little or no change in blood flow to torso skin, but marked increases in flow to the extremities. During severe hyperthermia, the increases in blood flow to lower leg and ear skin were reduced in the sheep (but not the dog) as though heat stroke might soon ensue (Hales 1983b).

Some of the bovine species and subspecies used extensively as draught animals use sweating, as well as panting, to lose heat (e.g. *Bos indicus*). Others, such as the water buffalo *(Bos bubalis)*, have a poorly developed capacity for sweating. Changes in skin temperature indicate marked cutaneous vasodilation during heat stress (Whittow 1962) but we are unaware of any blood flow measurements.

RESPIRATORY MUSCLE

Not surprisingly heat stress causes major increases in blood flow to the respiratory muscles in panting animals, in which respiratory frequency can exceed 300 breaths/min. In the sheep (Hales 1973b) and dog (Hales and Dampney 1975) blood flow to the crus muscle and diaphragm can increase as much as 10-fold, to levels never approached during maximal contraction of non-respiratory skeletal muscles. In both species % CO to the crus, diaphragm and intercostals increased from <3% in thermoneutral conditions to 10–17% during severe heat stress.

NON-RESPIRATORY MUSCLE

In the sheep (Hales 1973b) and baboon (Hales et al. 1979), blood flow (ml/min) to whole-body muscle decreased during mild to moderate heat stress, whereas in the dog (Hales and Dampney 1975), muscle blood flow tended to increase, although not as much as CO. In the sheep the heat-induced decline in muscle blood flow was reversed during the latter stages of severe heat stress, when Tc had increased by more than 2°C and slower, deeper panting and respiratory alkalosis prevailed.

ABDOMINAL VISCERA

Major decreases in renal and splanchnic blood flows have been observed in the heat-stressed sheep (Hales 1973a) and baboon (Hales et al. 1979). This redistribution of blood flow assumes added significance because, as noted earlier, CO is relatively unaffected by heat in these species. In contrast, the dog appears to rely mainly on increased CO to supply the increased blood flow requirements of the respiratory muscles and skin. Nevertheless, relatively unchanged renal and gastrointestinal flows in the face of increased CO could be regarded as a form of redistribution of blood flow, since % CO to these organs clearly decreased during severe heat stress (Hales and Dampney 1975).

OTHER TISSUES

In the heat-stressed baboon, adipose tissue blood flow decreased significantly in the perirenal and omental but not the subcutaneous region (Hales et al. 1979). Total adipose tissue mass was not measured so the quantitative significance of this observation is unclear. However, in sheep exposed to mild heat stress, whole-body adipose tissue blood flow decreased from 16 to 10% CO (Hales et al. 1984; Fig. 2). This represented a decrease in absolute flow of about 260 ml/min, which would easily have accounted for increased flow to skin and respiratory muscles.

There are other species differences in blood flow distribution which are related to thermoregulatory mechanisms. Although the dog and sheep both pant, increases in blood flow to the naso-buccal regions, particularly the tongue, were much greater in the dog (Hales and Dampney 1975; Plescka 1980), an open-mouthed panter, than in the sheep (Hales 1983a) which pants through the nose and only opens its mouth when Tc is raised by more than about 1C°.

ARTERIOVENOUS ANASTOMOSES

Under thermoneutral conditions in which skin vasodilation is minimal about 2% of CO in sheep appears to pass through AVAs, most of which are probably located in skin, but during heat stress this fraction can exceed 10% CO (Hales 1983a). In the dog and baboon about 5 and 9% of CO, respectively, bypasses the systemic capillary circulation during heat stress.

Combined Effects of Exercise and Heat Stress

The nature of the cardiovascular problems posed by the combination of exercise and heat stress has been extensively studied in human subjects (see reviews by Rowell 1974, 1983; Nadel 1980). These problems have not been examined although they are potentially important for draught animals, the great majority of which have to work in the tropics. In smaller ruminants, the only detailed studies appear to be those of Bell et al. (1983) on sheep and Feistkorn et al. (1984) on goats.

Humans

In humans, the capacity for increasing CO at a given level of upright exercise in hot versus cool environments is limited, because several factors operate to reduce central blood volume and thus, venous return to the heart and stroke volume. These include: a major increase in the volume of blood in skin; decreases in blood plasma volume due to increased capillary filtration in contracting muscle; and loss of body fluid in sweat. Since further major increases in CO are clearly out of the question, any heat induced modifications to the distribution of CO during exercise assume a critical importance as the only remaining major strategy for maintaining both circulatory and thermal stability during physiologically tolerable combinations of exercise and environmental heat.

Exercise-induced decreases in splanchnic and renal blood flows are greater in hot than in cool environments, but the combined reductions in these

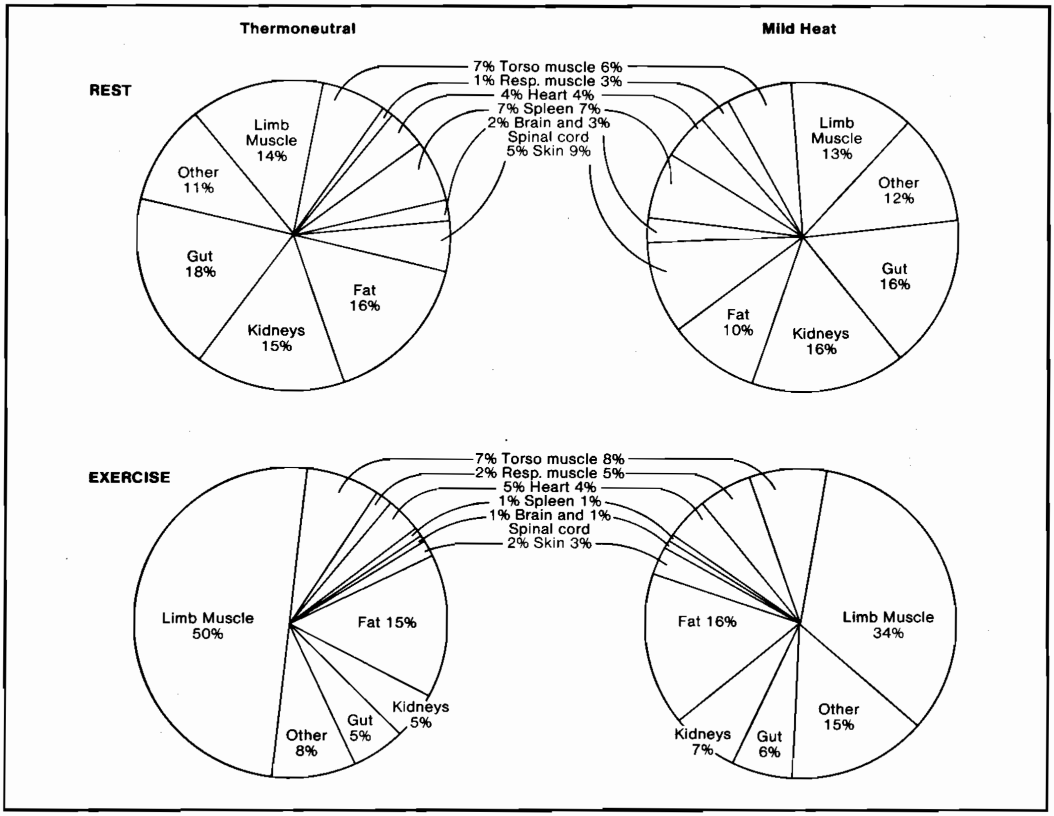

Fig. 2. Effects of exercise and mild heat stress on the distribution of cardiac output (means for 5 sheep). Relative values for cardiac output are represented by circle areas.

flows during moderate to heavy exercise in the heat are unlikely to provide sufficient blood for sweating skin and/or exercising muscle (see Rowell 1974). More recently, it has been shown that skin is relatively vasoconstricted under these conditions (Johnson et al. 1974; Brengelmann et al. 1977; Nadel et al. 1979). This vasoconstrictor response appears to be the mechanism for avoiding the circulatory collapse which would presumably occur if accumulation of blood in cutaneous capacitance vessels continued unabated simply to meet thermoregulatory demands. The relation between Tc and skin blood flow during heat exposure is also modified by state of hydration. Hypohydration of human subjects during exercise in the heat, which decreased stroke volume and CO, caused an elevation in the Tc threshold for cutaneous vasodilation and reduced maximal skin blood flow by about 50% (Nadel et al. 1980). Blood flow to exercising muscle may also be compromised by competition with skin (Rowell 1974; 1977), but direct evidence in humans is lacking.

Sheep and Goats

The circulatory consequences of combined heat and exercise stresses in these species might be expected to be less drastic than in humans for several reasons; firstly, the sheep does not distribute nearly as large a fraction of its CO and blood volume to skin as does man; secondly, venous return of the quadruped will be much less affected by gravity than that of upright man, under any conditions; and thirdly, ruminants have a considerably larger gut from which to redistribute blood flow than does man and other non-ruminants. This has been borne out by our observation that CO, heart rate, mean arterial pressure and total peripheral resistance were not significantly affected in sheep exercising in a hot (40 °C) environment. Changes in rectal temperature, $\dot{V}o_2$ and CO under these conditions are shown in Fig. 3. Effects of Tc have been examined more specifically in goats exercising at 35 °C, with their body temperatures clamped at 39°, 40.5° or 42 °C (Feistkorn et al. 1984). Once again there was little effect of Tc on central cardiorespiratory parameters.

In contrast to the gross cardiovascular parameters, exercise-induced changes in the distribution of CO in sheep were altered considerably by heat exposure (Fig. 2; Hales et al. 1984). In particular, there was a major decrease in the fraction of CO going to non-respiratory muscles. This decrease amounted to about 1600 ml/min, which was more than sufficient for both the decrease in CO and increases in flow to respiratory muscles (for panting) and skin. Thus, a 'balanced' cardiovascular response was actually measured—something not previously done in man or other species.

Several other features of Fig. 2 warrant comment. Surprisingly, and in contrast to humans, % CO to the kidneys was actually significantly higher during exercise in MH compared with exercise in TN. Absolute renal blood flow was also significantly increased. We have no explanation for this apparent failure to redistribute the available blood volume, unless this renal flow is needed for renal compensation of the respiratory alkalosis which can develop in panting animals. Also in contrast to humans, there was no further decrement in % CO to any of the splanchnic tissues. In addition, the estimated fraction of CO perfusing adipose tissue was unaltered during exercise in the heat.

The results summarised in Fig. 2 do not indicate whether working or resting muscle, or both, were sites of decreased blood flow during MH. However, when % CO to individual muscle groups was compared it became apparent that most, if not all, of the decrease was confined to locomotory muscles in the limbs. In contrast, % CO to torso muscles was quite unaffected. We do not know whether decreased blood flow was accompanied by reduced metabolism in exercising muscle. However, in sheep undergoing a similar level of exercise in thermoneutral conditions, there was a substantial reserve in the oxygen content in venous blood draining the active hindlimb, which was greater than 40% of arterial oxygen content (Bird et al. 1981).

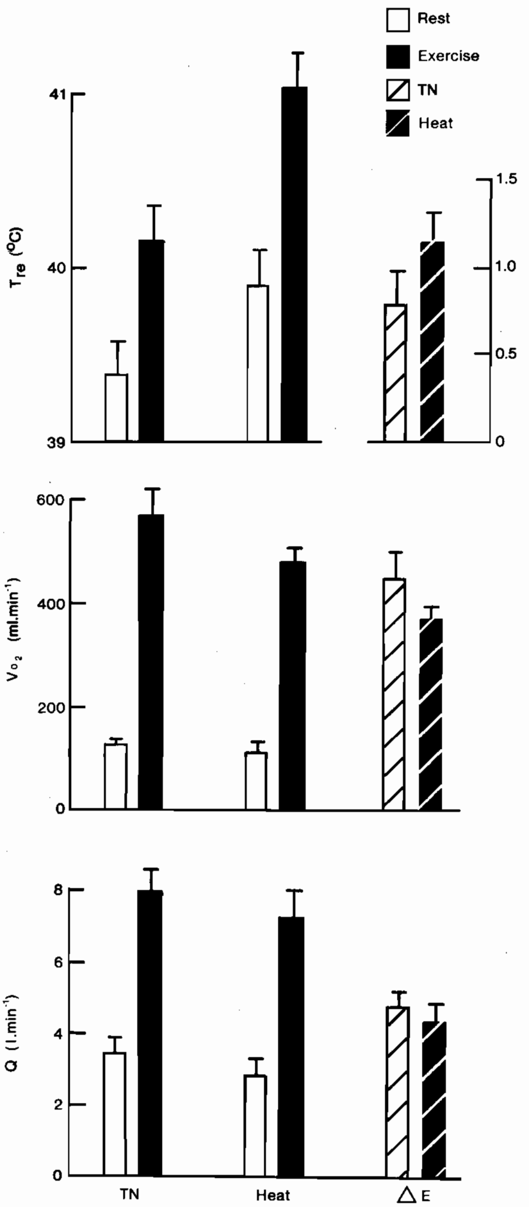

Fig. 3. Responses of rectal temperature (Tre), oxygen consumption ($\dot{V}O_2$) and cardiac output ($\dot{Q}$) to 30 min exercise in thermoneutral (TN) and hot environments. Means ± SE (n = 5) of absolute levels and changes with exercise (ΔE).

Exercise and Heat Stress During Pregnancy

Physiological responses to exercise during pregnancy have been recently reviewed (Lotgering et al. 1985). In pregnant ewes, moderate to severe treadmill exercise caused a 20–40% decline in uterine blood flow (Clapp 1980; Chandler and Bell 1981; Lotgering et al. 1983a; Bell et al. 1984; Chandler et al. 1985). This was associated with the development of moderate fetal arterial hypoxaemia, which persisted during maternal exercise, but usually disappeared soon after exercise ceased (Chandler and Bell 1981; Lotgering et al. 1983b). A more serious consequence of maternal exercise may be the elevation, and slow decline during recovery, of fetal Tc (Lotgering et al. 1983b; Fig. 4), as the duration of a

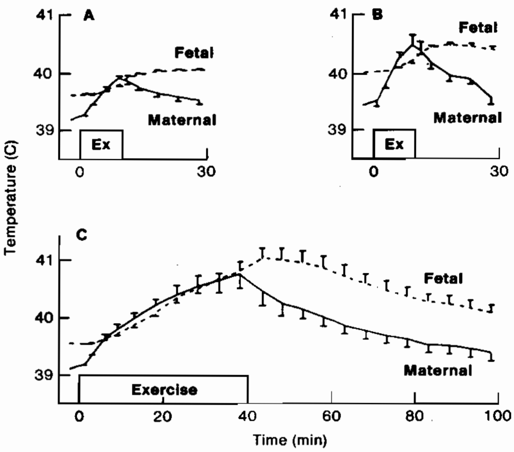

Fig. 4. Effects of maternal exercise on maternal and fetal body temperatures (from Lotgering et al. 1983b, with permission of the authors and the Journal of Applied Physiology).

level of hyperthermia is a critical determinant of the ultimate significance of a particular temperature level.

Prolonged heat exposure during mid and late pregnancy causes fetal growth retardation in sheep (Alexander and Williams 1971) and cows (Reynolds et al. 1985). This could be attributed to a decreased uterine blood flow, which has been observed in sheep exposed to severe heat stress for several hours (Oakes et al. 1976; Brown and Harrison 1981) or more importantly, during mid pregnancy, in ewes (G. Alexander and J. R. S. Hales, unpublished data) and Hereford cows (Reynolds et al. 1985) chronically exposed to levels of environmental heat commonly encountered in tropical countries (Table 3). In ewes returned to a cool environment in late pregnancy, after heat exposure between 50 and 120 days of gestation, both uterine and umbilical blood flows were permanently reduced (A. W. Bell and G. Meschia, unpublished data).

Table 3. Effects of chronic heat exposure on uterine blood flow (l/min) in ewes (Alexander and Hales, unpublished data) and cows (Reynolds et al. 1985). Values are means ± SE (no. animals).

	Ewes (99 days gestation)	Cows (169 days gestation)
Control*	0.695 (6)	6.12 ± 0.49 (8)
Heat**	0.480 (4)	4.27 ± 0.62 (5)

Temperatures, dry bulb/wet bulb

* Ewes—18/12 °C; Cows—18/12 °C.

** Ewes—43/27 °C for 9 h/d, 32/19 °C for 15 h/d for 20d;
Cows—36/27 °C for 12 h/d, 28/23 °C for 12 h/d for 69 d.

Late pregnant ewes stressed by exercise and mild heat (Tdb = 40 °C) appeared to cope as well as their non-pregnant counterparts (Bell et al. 1983; 1984). Although they developed a greater degree of hypocapnoea and respiratory alkalaemia than during exercise in a cool environment, the exercise-induced decrement in uterine blood flow (∿30%) was unchanged by heat exposure (Bell et al. 1984). Also, the effects of heat exposure on exercise-induced changes in blood flows to exercising muscles and visceral tissues, observed in non-pregnant sheep (Bell et al. 1983), were largely absent in pregnant ewes. This suggests that the substantial fraction of uterine blood flow which is available for redistribution may actually enhance the capacity of the pregnant animal for exercise. However, prolonged work, particularly in the heat, is likely to have deleterious effects on fetal oxygenation, body temperature and growth (see Lotgering et al. 1985).

Limits to Work Output in Hot Environments

What limits the ability of animals to work in the heat, and how is this related to conflicting requirements for the distribution of blood flow? In humans, it seems reasonably clear that a major limiting factor is the threat of circulatory collapse, for which a degree of cutaneous vasoconstriction is an attempted compensation but exacerbates the hyperthermia. In the goat, which is a panting animal, circulatory integrity appears to be less threatened and it has been suggested that temperature-dependent accumulation of lactic acid in exercising muscle may limit the ability to exercise during heat exposure (Feistkorn et al. 1984). This could be related to muscle hypoxia, associated with the smaller degree of exercise hyperaemia in the heat (Bell et al. 1983). Alternatively, lactate production and/or release by muscle may have been stimulated by respiratory alkalosis, the depth of which increases with Tc.

The capacity of the evaporative heat loss mechanisms is smaller in panting than in sweating species (Taylor 1977). The ability to lose heat by panting is probably limited by the metabolic rate and/or biomechanical properties of the respiratory muscles rather than their blood supply, since their blood flow rate (Hales 1973b) is markedly higher than that ever reported for exercising muscles and the fraction of CO involved is low relative to, say, that going to skin in man under similar conditions. Although the overall metabolic cost of panting is relatively low at rest, at least in sheep and cattle, this is only because of concomitantly reduced metabolism in tissues other than the respiratory muscles (Hales and Brown 1974); this could not occur during severe exercise without some penalty.

Physiological limits to working ability in tropical draught animals have not been systematically studied. Species differences in the relative importance of sweating and non-sweating mechanisms for heat dissipation could be important. For example, in Zebu (*Bos indicus*) cattle sweating is considerably more important than panting (MacFarlane 1968), whereas the water buffalo is poorly supplied with sweat glands and needs to wallow to assist cutaneous evaporative heat loss. Not surprisingly, buffaloes became stressed much more quickly than Indian cattle when exposed to intense solar radiation (Mullick 1960).

Within a given species and breed, a number of other factors and their interactions are likely to affect working ability in hot environments. These include a possible interaction between physical training and heat tolerance, as observed in humans (Roberts et al. 1977), and effects of feed and water intakes. For instance, the ability to endure enforced walking in a hot environment was lower in Hereford steers on a high plane of nutrition than in those fed to lose weight (Murray et al. 1981). Further, exercise-induced increases in Tc were found to be greater in steers on a restricted water intake and, although this did not appear to be caused by decreased sweating rates (Schmidt et al., 1980), water restriction will commonly reduce cutaneous vasodilation, sweating and panting ability.

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Changes in Body Temperature and Working Efficiency of Thai Swamp Buffalo

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BUFFALO have been of economic importance in Thailand for centuries. According to the Agricultural Statistics of Thailand in 1982, there were 6.4 million head in the country, with 60% in the Northeast. Most Thai farmers raise buffaloes, primarily draught animals, for ploughing their croplands. The use of buffalo for draught is quite suitable economically and socially, especially for farmers who live in remote areas and who own only small parcels of land and family labour is available when needed. Although many farmers would prefer to use machinery, the shortage of petroleum products demands that renewed attention be directed to the use of buffalo power in Thailand.

Drought resulting from inadequate amounts or poor distribution of rainfall is a serious problem in many areas of Thailand. There are, however, supplies of water available in natural sources such as streams, ponds or in aquifers at shallow depths. Economical methods are needed for lifting such water and distributing it to sites where it could be used effectively. Buffaloes may have an important role in providing such power rather than using gas-powered machines. Little or no research has been done on this problem, although buffaloes are still used with old water-lifting devices in some areas such as Lampang Province in Northern Thailand.

The present effort is to study the use of buffaloes for the operation of a water-lifting device. The aims of this research are: (1) to study the buffalo behaviour while operating the water-lifting device; (2) to study the changes in body temperature of buffalo within one working hour; (3) to study the efficiency of buffalo power for operating the water-lifting device; and (4) to study the efficiency of buffaloes during different periods of time during the day.

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Literature Review

Although the buffalo has been used as a draught animal for a very long time in Thailand, very little research has been done in this area. A study on the physiological consequences in the buffalo resulting from work has not yet appeared, but it is, however, relevant to review the physiological conditions and the working ability of Thai swamp buffalo here.

Physiological Characteristics

Very little research on the physiology of Thai swamp buffaloes has been conducted.

Harber (1980) studied 42 newborn calves in the northeastern villages of Thailand. He found that the average body temperature was 38.6 °C, the pulse rate 177.8/min, and the respiration rate 59.2/min. Harber and Usanagornkul (1981) reported the body temperature of 65 new born calves at Surin Buffalo Research Center which was not different from the former (38.5 °C). It was also observed that the value could rise physiologically to an average of 40.1 °C after sunbathing and after a long walk (about 1.5 km) from the pasture to the night corral.

Chantaraprateep and Bodhipaksa (1975) observed the general body condition of six male buffalo 3–5 years of age. The same parameters were examined by Teinkhao and Teinkhao (1978) in mature buffalo bulls. The average values of respiration rate, pulse rate, and body temperature were 20/min (167 animals), 30/min (165 animals), and 37.7 °C (80 animals) respectively.

Climatic Effects

Heat Tolerance

While the buffalo is remarkably versatile, it has poorer physiological adaptation to extremes of heat and cold than the various breeds of cattle. Body temperatures of buffaloes are actually lower than those of cattle, but the buffalo skin is usually black and heat-absorbent and only sparsely protected by hair. Also, buffalo skin has one-sixth the density of sweat glands that cattle skin has, so buffaloes dissipate heat poorly by sweating. If worked or driven excessively in the hot sun, a buffalo's body temperature, pulse rate, respiration rate, and general discomfort increase more quickly than those of cattle. Buffaloes prefer to cool off in a wallow rather than seek shade. They may wallow for up to 5 hours/day when temperature and humidity are high (NRC 1981).

Recent Studies in Thailand

The comparative study of physiological characters of swamp buffaloes between two different time periods was investigated by Sripongpun (1976). The number of animals used was six females, 3–4 years of age, kept in an open-shed barn. The mean of respiration rate at noon was not different from the evening (30.7 vs 30.9/min), while the pulse rate and the body temperature in the evening were significantly higher than at noon (56.3 vs 49.7/min and 39.1 vs 38.4 °C).

Chaiyabutr et al. (1983) reported the effect of heat exposure on physiological changes of swamp buffaloes, 3–4 years of age. The buffaloes were exposed to the summer sun (April–July) for 4 hours. The respiration rate began to increase by 52% by the first hour and by nearly four times on the fourth hour. It was observed that the heart rate relative to respiration rate increased very little after 1 hour of sun exposure, but significantly increased after 4 hours. Rectal temperature of buffalo rose from 38.9 °C to 40.4 °C after 4 hours of sun exposure.

Prucsasri (1983) studied the diurnal changes of three physiological responses of swamp buffaloes to the ambient temperature and compared them with similar data for cattle. It was found that changes in body temperature, respiration rate, and pulse rate of buffaloes significantly positively correlated with the changes of ambient temperature. In cattle, the relationship between the ambient temperature and body temperature was significantly positive, but that the pulse rate was not significant, and the respiration rate was negative.

Working Ability

The greatest numbers of buffaloes in Thailand are used for draught mainly in rice production; for ploughing and harrowing the paddy fields, for rice threshing and milling, and for transportation. In some areas, farmers used them to turn sugarcane crushers and water-lifting devices. Buffaloes are well suited to work in muddy and submerged fields where they are able to pull heavier loads than cattle (Chantalakhana 1975). Training buffaloes for work begins at the age of 3–4 years. Most Thai buffaloes work for 5 hours a day, each plough about 0.1 hectare per day (Buranamanus 1963; Rimkiree 1984). Their hard working period is from May to September, which is the rice-growing season (Buranamanus 1963). Therefore, the shortage of buffalo power usually occurs during that period (Ratanadilok Na Puket 1979). Cockrill (1974) compiled information concerning the working periods of buffaloes in certain regions of Thailand. It was found that buffaloes worked from 66 to 146 days per year (average 122).

A very recent study by Konanta et al. (1984) reported the working performance of Thai swamp buffalo compared with crossbred Murrah under feed supplementation at Surin Buffalo Research Center. The former seemed to work better than the latter as shown by the results of area ploughed and walking speed.

Besides the reports on working ability of buffalo in the paddy fields, its efficiency in pulling a cart and turning a sugarcane crusher in terms of speed has been studied (Rimkiree 1984).

In addition, Chantalakhana (1983) stated that most reports available in the past gave only general working ability of buffalo (Rife and Buranamanus 1959; Buranamanus 1963; De Boer 1971; Rufener 1971; Bhannasiri 1975; Monkonpunya 1978; Niumsup and Songprasert 1978).

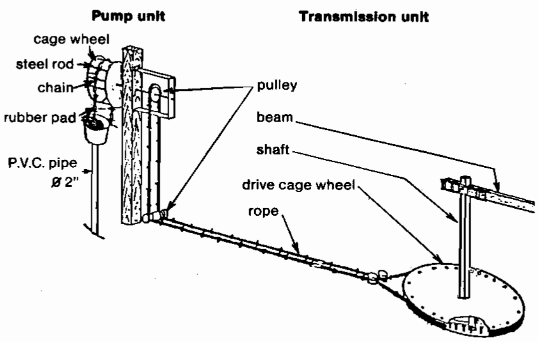
Present Study

Buffalo

Four male buffaloes used in our research belonged to the Rice Division, Department of Agriculture. They were raised for ploughing land which is used for experimental rice plantings. Their weights, estimated by measuring heart girth (Ratanaronchart 1974) were 656, 674, 608 and 608 kg, respectively. The animals were approximately 20 to 25 years old. Their feed is usually obtained from natural grass when stockmen drive them to graze along both sides of the roads. When the weather is very hot, the buffaloes may wallow in water ways, taking water hyacinth as their feed. During the trials, silage was provided for the animals.

Water-Lifting Device

The water-lifting device used in these trials was constructed by Thai engineers and consists of two units: the pump and the transmission (Fig. 1). The construction materials used to make this device were those which would be readily available in rural areas.



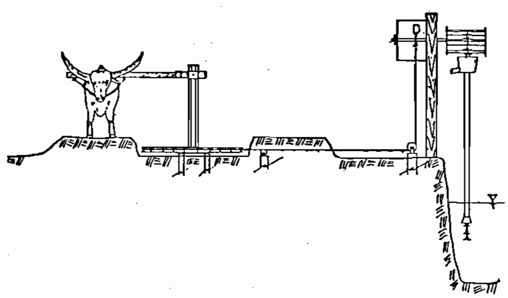


Fig. 1.
Top—Driving mechanism of water-lifting device.
Bottom—Schematic illustration of buffalo at work.

The water-lifting device operated by buffalo power was installed on the bank of a ditch in the area of the Rice Division, Department of Agriculture, on the east side of Suwanwajokkasikit Road. The study period was about 3 months (April 18 to July 20, 1983).

PROCEDURES

1. The animal harness system to operate the water-lifting device was to place the free end of the power lever atop the neck of the buffalo. A rope was tied to the end of the lever, then passed under the neck of the buffalo and tied to the lever on the other side of the neck. Care was taken to be sure the rope was not too tight. The buffalo was directed to walk in a circle by the stockman who followed behind and outside the path of the animal. Before collecting data, each animal was trained on 2 or 3 occasions for periods of 30 min.

2. Four 1-hour work periods during a day were set as follows: 7.30–8.30, 9.00–10.00, 1.30–2.30; and 3.00–4.00 pm. The buffaloes worked in each of the four time periods. While working, revolutions/min and steps/min were recorded in the first and the second half of each hour.

3. The buffalo body temperatures were measured before and after 1 hour of work using a rectal thermometer. The ambient temperature was also recorded.

4. The buffalo behaviour was observed during each working hour.

DATA ANALYSES

1. Changes in body temperature and the efficiency of individual animals in the first and the second half of an hour were analysed by paired comparison (Chantalakhana 1976).

2. Analysis of variance was used to test the significance of differences of working efficiency of buffaloes in different time periods during a day. The design involved samples within samples, with unequal sample sizes (Chantalakhana 1976).

Results and Discussion

Buffalo Behaviour

When the buffaloes were first required to walk in a circular pattern, they reacted adversely and became very difficult to handle. Therefore, they had to be trained by a very skilled stockman or operator under whom they could be controlled. He used a stick lightly on their hind quarters to encourage them to follow the correct course until they became familiar with it.

During the first 15 days, the experimental buffaloes, generally, groaned and slavered as they worked. Often they stopped walking and opened their mouths widely. This was especially true during the last 30 min of a working hour. Some tried to gore the lever, resisting the requirement to walk in a circular direction. Strangers passing close to the animals always frightened them. After about 15 days, the buffaloes became accustomed to the pattern of the experiment, and their strange behaviour largely disappeared.

The four experimental animals have been used for ploughing paddy fields for a long time. They responded only to the orders of the two stockmen who have raised them for over 20 years. According to these stockmen, these animals could be rated as being highly efficient animals for ploughing. While ploughing they were accustomed to walking in a straight path, whereas in this experiment they were forced to walk in a circle to move the water-lifting device. Their adverse reactions appeared to be because of unfamiliarity with the pattern. Groaning

Table 1. Changes in body temperature and working efficiency of individual buffalo operating the water lifting device (X ± SD).

Buffalo number	1	2	3	4
Weight (kg)	656	674	608	608
No. of observations	32	13	59	25
Ambient temp. (°C)	34.01 ± 5.22	36.67 ± 5.50	33.43 ± 4.07	33.84 ± 3.43
Body temp (°C)				
Initial	38.06 ± 0.17	37.73 ± 0.63	37.99 ± 0.17	38.04 ±0.14
Final	39.03 ± 0.12	38.54 ± 0.63	39.00 ± 0.21	39.00 ± 0
Difference	0.97**	0.81**	1.01**	0.96**
Revolutions/min				
1st half	2.84 ± 0.26	3.65 ± 0.44	3.10 ± 0.38	2.91 ± 0.41
2nd half	2.83 ± 0.30	3.58 ± 0.45	3.20 ± 0.37	2.99 ± 0.30
Difference	0.01^{ns}	0.07^{ns}	-0.10*	0.08^{ns}
Steps/min				
1st half	66.80 ± 5.79	68.54 ± 21.72	70.46 ± 7.22	64.36 ± 5.49
2nd half	66.31 ± 4.91	74.81 ± 8.22	71.43 ± 7.48	65.98 ± 6.32
Difference	0.49^{ns}	-6.72**	-0.97^{ns}	-1.62*
Average step length (m)	0.67	0.79	0.70	0.71
Average speed[a] (km/hr)	2.67	3.40	2.97	2.78

[a] The lever length from centre of the base to the middle point of the neck of the buffalo is 2.5 m.

ns = non significant, * = significant at 5% level, ** = significant at 1% level

and slavering may be signs of uneasiness. Opening the mouth widely may be a way to take in more oxygen. The harness used was also different from that used in pulling the plough. Some animals adjusted rather easily, while others were quite disturbed and tried to gore the lever. However, all animals later worked well within the time set.

Changes of Body Temperature

Working during 1 hour of exposure to the sun caused temperatures of all four buffaloes to rise (P 0.01) 0.97°, 0.81°, 1.01 and 0.96°C, respectively (Table 1). Similarly, Chaiyabutr et al. (1983) reported from an experiment in Thailand that after 4 hours direct sun exposure temperatures of buffalo rose every hour from an initial reading of 38.94°C to 39.17, 39.56, 40.17, and 40.39°C, respectively. During one trial in Egypt, 2 hours of working exposure to the sun caused temperatures of buffaloes to rise 1.30°C (NRC 1981).

Efficiency of Buffalo Power

The working efficiency of four buffaloes was compared as shown in Table 1. The revolutions/min of three buffaloes between the two halves of a working hour were not significantly different (2.87 vs 2.83, 3.65 vs 3.58, 2.91 vs 2.99), while for one buffalo there was a significant increase from 3.10 to 3.20. The numbers of steps per minute were also compared. Two animals had no significant change in the two halves (66.80 vs 66.31 and 70.46 vs 71.43). One animal had more steps/minute in the second half (64.36 vs 65.98). The fourth animal had a highly significant increase in the second half (68.54 vs 74.81).

These results showed that buffaloes worked well in a whole period of 1 hour. Some individuals walked faster in the second 30 min. Therefore, buffaloes were able to work without any break for 1 hour while operating the water-lifting device. Further experiments should be conducted over periods longer than 1 hour to get more information on the efficiency curve.

In this study, the average walking speed and the average length of step for the four buffaloes were 3.08 revolutions/min or 2.9 km/hour, and 0.7 m, respectively. Similarly, Rimkiree (1984) observed buffaloes walking in a circular pattern to turn a sugarcane crusher at an average speed of 3.0 km/hour.

The relative efficiency of buffalo in four different time periods during a day was calculated in terms of revolutions/minute and steps/minute. Differences were not significant (Table 2), however, the results indicated that buffaloes worked more efficiently in the morning than in the afternoon. This observation agrees with farmer experience since they generally use the buffaloes to plough in the morning while the temperature is cooler and let them graze and wallow in the afternoon. Chantalakhana (1981) had also stated that working efficiency of buffaloes

Table 2. The efficiency of buffalo power operating the water-lifting device in four different time periods (X ± SD).

Periods of time	n	Steps/min	Revolutions/ min
7.30–8.30 am	35	70.64 ± 5.71	3.12 ± 0.32
9.00–10.00 am	34	68.76 ± 7.00	3.12 ± 0.41
1.30–2.30 pm	30	67.76 ± 7.27	3.02 ± 0.37
3.00–4.00 pm	25	68.71 ± 5.18	3.01 ± 0.26

was affected by heat. They like to wallow in water, and particularly in mud, when the temperature is high. In shade or in wallow buffaloes cool off quickly, perhaps because a black skin rich in blood vessels conducts and radiates heat efficiently (NRC 1981).

Conclusion

From a thorough review of work done in Thailand on physiological changes in buffalo, including this investigation, we conclude that much research remains to be done in this area. Future priority research in Thailand, therefore, should emphasise basic physiological studies in working buffalo and cattle.

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Physiological Changes Associated with Work: Some Lessons from the Horse

R. Anne Pearson*

MUCH of the information available on the physiology of exercise has been obtained, not surprisingly, from studies on animals involved in leisure sports. Physiological changes associated with exercise and repeated exercise are reasonably well documented for the athlete and the racehorse, the elite well-nourished performers. More recently with the popularity of marathon running and endurance riding the effects of prolonged exercise on the average performer have also been studied. Although there are many more animals kept for draught purposes than for competition throughout the world, there is little information available on exercise in draught animals. This is particularly true of the draught ruminant, possibly regarded as the poor relation of the racehorse. Unlike the racehorse or athlete it is not always well fed and often has to work for long periods of time at high environmental temperatures.

In this article factors influencing an animal's ability to do work are examined and some of the physiological consequences of exercise are discussed, drawing on information obtained from the study of equine exercise physiology. The application of physiological measurements to draught animals is considered in the final section.

Metabolic Factors Affecting Work Capacity

In its role as a power source in agriculture and transport a draught animal can be thought of as a 'machine' which converts chemical energy into mechanical energy. At the same time other functions such as maintenance, growth and milk production compete for the energy supply. Conversion of chemical to mechanical energy is accomplished by muscle tissues. The success with which the animal carries out this process will depend on its ability to supply energy to the tissues and to use it.

Energy for Muscle Contraction

The immediate source of energy for muscle contraction is ATP. The energy released is used directly by the contractile mechanism:

$$ATP + H_2O \xrightarrow{\text{myosin ATPase}} ADP + Pi + H^+ + Energy$$

The concentration of ATP in skeletal muscle is very limited and if muscle contraction is to continue for more than a second or two ATP must be resynthesised. This resynthesis is achieved by two distinct processes, aerobic phosphorylation and anaerobic phosphorylation.

Aerobic Metabolism

At low work rates (submaximal exercise) energy is provided by aerobic metabolism of substrate (largely NEFAs) using oxygen provided by the blood circulation. The rate of oxygen transport to the tissues can meet the demand and ATP used up during muscle contraction can be replenished by aerobic phosphorylation. This involves the reduction of substrates from fat and carbohydrate metabolism and their subsequent oxidation in the TCA cycle in mitochondria. Aerobic metabolism is a relatively slow process because of the complexity of the reactions and the cardiovascular delay in supplying oxygen. It can take up to 60 sec to reach full aerobic production (McMiken 1983), however the yield of energy is high. The oxidative production of ATP from glycogen yields 36 moles of ATP per mole of substrate.

Anaerobic Metabolism

At high work rates (maximal exercise), rate of muscle contraction or degree of contraction is increased as more muscle fibres are activated. The maximum rate at which oxygen can be supplied to the muscle cells is exceeded and the aerobic energy pathways can no longer entirely meet the demand. In this situation, anaerobic regeneration of ATP from creatine phosphate, ADP and the conversion of pyruvate to lactate during anaerobic glycolysis provides additional energy at a rapid rate (within 1 sec) to the muscle cells. The energy yield from this process is much lower than that from oxidative processes. From glycolysis the yield is only 2 or 3

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moles ATP per mole of substrate (depending on the substrate) and for creatine kinase and myokinase the yield is only 1 mole ATP per mole of substrate used. The rapid provision of energy cannot be sustained for long as anaerobic substrates notably glycogen and glucose are soon depleted and work rate has to decrease. Hence maximal effort can be reached rapidly but cannot be sustained. Even the horse which has a high glycogen storage capacity can maintain top speed for only about 800 m when galloping (McMiken 1983).

Physiological Work Capacity

In the exercising animal aerobic and anaerobic metabolism proceed simultaneously. All energy pathways are used in the muscle to some degree at all workloads. At low rates muscle lactate is oxidised by neighbouring fibres or removed by gluconeogenesis so blood lactate does not increase beyond an initial equilibrium. With increased work rate there is a point at which blood lactate concentrations increase progressively because the production of lactate exceeds its removal from the bloodstream. This point has been defined as the anaerobic threshold.

Draught animals are generally believed to perform work at submaximal exercise levels well within the limits of aerobic metabolism. However, short-term increases in work rate are often required—e.g. when moving off with a laden cart, freeing an implement from rough ground or working uphill—when the animal may operate at maximal level, making demands on its energy reserves during increased anaerobic metabolism. This may lead ultimately to fatigue and reduced work output during the day if the energy reserves are not 'topped up'.

Clearly the more effective the aerobic metabolism is then the greater will be the reserves of anaerobic energy available. These reserves may be used gradually to enable the animal to work at a higher average rate over an extended working period or saved for a maximum effort over a short period. In either case the animal will work better than if it has to use the limited reserves merely to maintain low work output.

Energy Supply and Utilisation

The main factors influencing energy supply and utilisation in aerobic and anaerobic metabolism are given schematically in Fig. 1. Anything that increases energy supply (e.g. training or nutrition) must increase an animal's work capacity. However, and equally true, anything that has a detrimental effect (e.g. disease) can reduce physiological work capacity. Basic physiological mechanisms such as muscle contraction, energy metabolism, respiration, circulation and heat dissipation are essentially the same in most mammals. It is the quantitative aspects which determine the differences in the supply and use of energy by the tissues doing work.

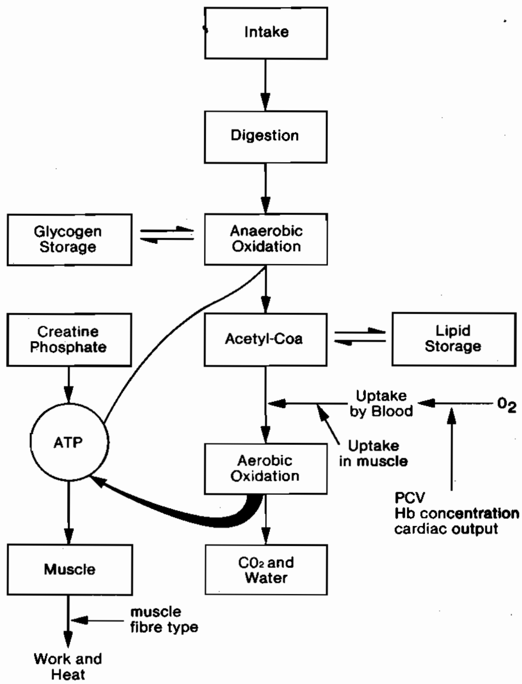

Fig. 1. A simplified scheme of the pathways from intake of chemical energy to the output of mechanical energy showing the main physiological factors influencing work output in an exercising animal.

Non-Physiological Factors Affecting Work Output

Physiological limitations are not the only factors limiting the ability of an animal to perform work. Psychological and physical characteristics and environmental factors must also be taken into consideration when relating physiological changes to the amount of work done. Temperament and training have a considerable effect on the amount of work an animal accomplishes. Coordination, gait and muscular strength, influenced by the size and conformation of the animal, similarly affect work output. Environmental conditions, terrain, soil type, design of implement and the motivation of the driver and his experience in handling animals also influence the work achieved during a particular period.

The Horse or the Ruminant for Work?

The horse is the only large working animal in which physiological and metabolic responses to graded exercise have been studied in any detail (e.g. Snow et al. 1983). Measurements of cardiovascular and respiratory responses to exercise, detailed studies of blood and muscle metabolites and more recently studies of muscle types have enabled the physiological changes associated with a range of different activities to be studied. Observations have shown that the horse, because of certain physiological advantages, has probably the greatest capacity for physical work of all domestic animals.

The advantage of the horse over other working animals is its unique ability to greatly increase the oxygen carrying capacity of its blood during exercise. The horse is capable of storing one-third to one-half of the total red cell volume in the spleen. Splenic contraction occurs in response to the sympathetic stimulation caused by exercise (Persson and Bergsten 1975), haematocrit and haemoglobin concentrations are elevated and the total circulating red blood cells can be increased by as much as 50% (Persson 1967; Thomas and Fregin, 1981). This enables the horse to increase its aerobic metabolism by up to 36 times during strenuous exercise (Thomas and Fregin 1981) compared with the two-fold increase observed in man (Astrand 1976) and the dog (Wagner et al. 1977). In addition, equine muscle has a high capacity for glycogen storage (over 126 mmol/kg) which provides considerable reserves for anaerobic metabolism (McMiken 1983). Glycogen reserves in skeletal muscles of cattle are lower, largely because the ruminant is dependent on hepatic gluconeogenesis of volatile fatty acids to provide most of the glucose and glycogen reserves (Judson et al. 1976), unlike the horse in which most glucose is absorbed directly from the gut. This does mean that the ruminant can survive on relatively high-energy diets whereas the horse, particularly when working, requires low-energy feeds if it is to maintain performance. In fact diminished endurance in grass-fed horses is a common observation.

The horse, like other animals, the dog (Wagner et al. 1977) and man (Smith et al. 1976) can increase cardiac output up to 5- to 6-fold in response to exercise (Persson 1967; Bergsten 1974; Thomas and Fregin 1981). However this does not entirely determine the delivery of blood to the working muscle because the requirements of other tissues have to be met. The need to supply blood to the skin for heat dissipation may constrain aerobic metabolism during exercise and has been observed to limit endurance performance in horses during events which lasted for several hours (Carlson and Mansmann 1974; Rose et al. 1979; Lucke and Hall 1980). The horse relies on evaporative loss by sweating as the main means of heat dissipation. Consequently a substantial loss of electrolytes and dehydration can occur during prolonged exercise (Rose et al. 1980a; Snow et al. 1982). Dehydration in the ruminant, which places less reliance on sweating, may be less of a problem particularly with the large but unpredictable reservoir of water in the rumen.

Bearing in mind the differences between the horse and ruminant during exercise, data from research on the horse may be helpful in determining which measurements to use in draught animal studies.

Changes Associated with Prolonged Exercise

Low blood glucose and high plasma NEFAs during endurance exercise in the horse (Rose et al. 1977; Snow and Mackenzie, 1977a; Lucke and Hall 1980) are consistent with NEFAs being the major energy source in prolonged exercise. Little change in lactic acid levels occur after the initial rise due to early glycolysis (Snow and Mackenzie; 1977a; Lucke and Hall, 1980; Dybdal et al. 1980). In fact alkalosis is a feature of prolonged exercise rather than the metabolic acidiosis associated with maximal exercise (Snow and Mackenzie 1977b). The former is probably caused by increased ventilation associated with the need to aid heat dissipation (Snow and Mackenzie 1977a). Plasma corticosteroids increase while insulin concentrations decrease during prolonged exercise (Dybdal et al. 1980). The anaerobic threshold is only reached in activities using sudden intense efforts such as polo (Craig et al. 1985) and 3-day eventing (Rose et al. 1980b), and is associated with a marked increase in plasma lactic acid concentrations. Detailed observations of biochemical changes in blood before and after training at submaximal levels have not shown any consistent changes in parameters which could be used to determine fitness (Snow and Mackenzie 1977a; Rose and Hodgson 1982) although training at maximal levels appears to improve the utilisation of glycogen and NEFA as substrates by working muscle (Snow and Mackenzie 1977b). Similarly, no consistent differences have been observed in the blood parameters of those horses that completed an endurance exercise compared with those that failed (Dybdal et al. 1980). Rose and Hodgson (1982) concluded that routine haematological and biochemical screening had no useful role in assessing the fitness of endurance horses.

Muscle Fibre Types

The evolution of distinct muscle fibre types in mammalian limb muscles effectively provides a gearing system minimising the energy cost of locomotion (Alexander and Goldspink 1979). Studies using muscle biopsy sampling with biochemical and histochemical techniques have provided information on the utilisation of substrates in specific fibre types in horses during prolonged exercise. Different types of fibre have been identified.

TYPE I

Known as slow twitch fibres, Type I have a contractile time about three times longer than fast twitch fibres. Histochemically they are rich in mitochondria and oxidative enzymes, and designed for a high rate of aerobic energy production. They are high in myoglobin content and have extensive capillaries which facilitate oxygen diffusion. The high energy yield and utilisation of oxygen give the Type I fibres great endurance qualities.

TYPE II

Histochemical staining has identified three types of Type II myosin ATPase in fast-contracting muscle which are designated Type IIA, IIB and IIC (Brooke and Kaiser 1970). Type IIA has fast-contracting properties but is also well equipped for oxidative energy production and therefore has good endurance properties. Type IIB fibres yield high rates of energy from intramuscular stores, having a high rate of energy release but limited endurance capacity. Type IIC fibres are present in only a small proportion, being more evident in very young animals. They seem to be a transitional stage in the development of new fibres and contain both fast and slow myosin (Snow et al. 1981a).

The different fibre types occur in different proportions in the various skeletal muscles. In addition the proportions of fibre types in a particular muscle vary between individual animals. The proportion of Type I and Type II fibres appears to be genetically determined and not altered by normal physiological adaptations. Snow and Guy (1980) studied the fibre composition in six limb muscles of different breeds of horse. They found the percentage of fast twitch fibres in the m gluteus medius varied significantly amongst breeds and these differences were related to the sprinting speed of the breed. The quarter horse had the highest percentage, followed by the thoroughbred, with the donkey and heavy hunter having the lowest proportion. Similarly some of the muscle enzymes activities could be related to the performance for which the animals were best suited. The quarter horse had the highest activity of the glycolytic/anaerobic enzymes and the glycolytic related enzymes (lactic dehydrogenase, aldolase and glycerol-3-phosphate dehydrogenase) and among the lowest activities of aerobic enzymes (citrate synthase, 3 hydroxyacyl CoA dehydrogenase) reflecting its high dependence on anaerobic metabolism for 400 m racing. The thoroughbred and Arab had the highest activities of aerobic enzymes when compared with the other breeds and in general the donkey had the lowest activities for all enzymes examined and the lowest concentrations of glycogen (Snow and Guy 1981). Within a breed (the thoroughbred) it is also possible to identify animals more suited to sprinting (1000–1600 m) or staying (2400 m–7000 m), the percentages of slow twitch fibres being significantly higher in the staying than the sprinting group (Snow and Guy 1981).

These observations were obtained in animals which had not undergone any recent training. However training of the animal is associated with some adaptation of fibre types. Along with maturation, training effects a transformation of some Type IIB fibres to highly oxidative Type IIA fibres (Lindholm and Piehl 1974; Guy and Snow 1977; Essen et al. 1980; Henckel 1983) so that fast twitch fibres may by adaptation develop good endurance qualities whilst retaining their high speed of contraction. No effect of training on slow twitch fibres has been observed. Training at submaximal levels also produces increases in the activities of muscle enzymes involved in oxidative metabolism (Snow and Guy 1979; Essen et al. 1980; Henckel 1983). In humans these increases are accompanied by a greater oxidation of fats and a reduced rate of glycogen depletion and lactate production by working muscle during submaximal exercise (Gollnick and Saltin 1982). In the horse, training also has a glycogen sparing effect (Lindholm and Piehl 1974). The animal's ability to utilise NEFAs and spare glycogen at least partly accounts for the varying degrees of glycogen depletion of equine skeletal muscle observed during prolonged exercise although severity of exercise will also have an effect (e.g. Hodgson et al. 1985). Snow et al. (1981) in a study of horses participating in an 80-km endurance race found varying degrees of depletion with a mean utilisation of approximately 60% of pre-ride glycogen concentrations. However, in a controlled study of horses examined at a constant speed (16–18 km/hr) Snow et al. (1982) found complete depletion in some thoroughbreds exercised for distances up to 80 km. Lindholm et al. (1974) observed considerably less glycogen depletion in standardbreds working at a similar speed over a slightly shorter distance.

Depletion usually occurs in Type I and Type IIA fibres first with the Type IIB fibres only being recruited in the latter stages (e.g. Snow et al. 1982; Hodgson et al. 1985). The pattern of repletion is the reverse of depletion and can be a slow process with none of the fibres being repleted 4 hours after exercise and only some being repleted after 24 hours (Snow et al. 1982).

Muscle Fatigue

McMiken (1983) suggested fatigue is not caused by a single factor but is the result of various occurrences associated with adaptation to different durations and intensities of exercise. While neural fatigue has been implicated in man, the accumulation of lactate in muscle has also been the basis of a hypothesis of muscle fatigue for many years. This may well be important in maximal exercise, however, lactate concentrations are usually low in prolonged exercise. Alternatively depletion of glycogen in muscle correlates well with the observed degree of fatigue in prolonged exercise in the horse (Snow et al. 1982). Clearly exercise fatigue is a complex phenomenon which is probably as yet incompletely understood.

Physiological Measurements and Their Application to Draught Animals

Measurements of physiological changes fall into two categories: (1) those suited to laboratory conditions, and (2) those that can be applied in the field. Draught animals are often working in hot, dusty, wet or muddy conditions and any equipment used to take physiological measurements under these conditions, all of which might be experienced in a single working day, needs to be robust and reliable. Laboratory studies, making use of treadmills, enable physiological changes to be observed in animals exercised under controlled conditions. These are necessary if physiological changes associated with work in draught animals are to be more completely understood. Cardiovascular and respiratory studies are more suited to a laboratory, whereas studies of blood and muscle parameters, although requiring fairly sophisticated analytical techniques often require larger numbers of animals than can be easily maintained in a laboratory. Measurements such as heart rate, respiration rate and body temperature are relatively easily measured in animals in the field, however, they do not provide a great deal of information. They can, however, be useful in comparative studies, e.g. heat tolerance of crossbred and purebred cattle. Clearly there is a need to look carefully at which measurements can be made in the field and which in the laboratory. The aim of any physiological study of draught animals should be to knit together observations made in the laboratory with field experiences so that a complete picture can be built up.

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Nutrition for Draught Power

A Review of the Nutrient Requirements of Draught Oxen

Peter R. Lawrence*

NUTRIENTS for any class of livestock are generally divided into four classes: vitamins, minerals, proteins and energy-giving nutrients. The requirements for these nutrients have been extensively investigated in beef and dairy cattle and tables drawn up in the form of feeding standards which tell one the amount of each type of nutrient required per animal according to its type, sex, age and physiological state.

For most nutrients it is customary to divide requirements into those for maintenance and those for production, i.e. growth, pregnancy and lactation. Since there is no reason to believe that the maintenance requirements of draught oxen differ from those of cattle kept for other purposes, the rationing of such animals becomes simply a question of determining the extra nutrients needed for work.

Vitamins and Minerals

There seem to be no significant extra requirements for vitamins and minerals in working animals over and above those contained in the extra food needed to supply the animal's increased energy needs. In very hot climates animals may need extra salt to replace that lost in sweat; there is seldom any lack of chloride ions in most diets, but forage crops in some tropical areas tend to contain very little sodium.

Protein

As in the case of vitamins and minerals, protein requirements seem to be minimal. Exercise seems to have little effect on urinary nitrogen excretion in man (Rennie et al. 1981) or sheep (Clapperton 1964). No work appears to have been done on draught animals, so the matter was investigated as part of the Centre for Tropical Veterinary Medicine (CTVM) project in Costa Rica.

Six oxen were fed 6 kg of hay and 3 kg of concentrate daily and nitrogen excretion in both urine and faeces were measured for 1 week while the oxen were at rest, 1 week when they used an amount of energy calculated to be 1.5 × maintenance followed by a further week at rest. The results (Table 1) show a small and statistically insignificant increase in urinary nitrogen excretion in the weeks during and after work compared with the week prior to work. The corresponding decrease in nitrogen balance is not large enough to be of any nutritional importance.

Thus there seems to be very little requirement for extra protein during work. If a working animal is not to lose weight, it must consume more energy-giving foods and this will almost certainly involve taking in enough extra protein as well. In the case of an underfed animal, the release of body reserves to meet the animal's need for energy will also involve the release of sufficient extra protein.

Energy

The Need for Energy

The most obvious extra requirement for draught animals is for energy. In general, a ruminant may need energy for any one of the following purposes: maintenance, pregnancy, growth, fattening, lactation and work. These are known as net energy requirements because in addition, an animal has to expend energy on the nutrients it absorbs in order to use them for any of the above processes. This extra energy is called a heat increment and can have different values according to the use to which the absorbed nutrient energy is put, e.g. an animal fed on medium quality hay would use about an extra 30 kJ of energy to provide 100 kJ for maintenance but about 50 kJ to produce 100 kJ of fat.

Classifying Energy-Giving Foods

Foods for ruminants can be classified according to how much net energy they contain and this forms the basis of the Net Energy (NE) system. The main drawback is that any particular food will have two or more net energy values according to what it is used for and up until now, comparatively few foods have had their various net energy values measured.

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Table 1. Nitrogen intake and average nitrogen excretion and balance of six oxen fed 6 kg of hay + 3 kg of concentrate daily.

	Intake	Excretion		Balance
	g/day	Faeces g/day ± S.D.	Urine g/day ± S.D.	g/day
Week 1—at rest	70.4	54.6 ± 3.1	14.0 ± 3.5	+ 1.8
Week 2—working at 1.5 × maintenance	67.3	50.7 ± 4.9	17.8 ± 3.4	-1.2
Week 3—at rest	67.6	52.2 ± 7.3	18.1 ± 3.0	-2.7

A more flexible system is that based on the absorbed or metabolisable energy (ME) system (MAFF 1975). The ME value of a food is rather easier to determine than the NE since it involves simply subtracting energy losses in the form of faeces, urine, and methane gas from the gross energy or heat of combustion of the food. A further advantage is that the ME value of a particular food tends to be fairly constant under most conditions. Standard values for the heat increments are then used to calculate the NE available for maintenance, growth, etc.

Fitting Working Animals into the ME System

To do this we need to know (a) how much energy will be needed for work, i.e. the NE for work, and (b) the heat increment associated with work. Combining (a) and (b) will then tell us the extra ME required for work which can then be translated into quantities of food.

The energy used by a working animal in the field cannot be determined directly. However, the amount and type of work can and this, along with the liveweight of the animal, enables an estimate to be made of the energy used for work. The information necessary to make these estimates can be summarised as:

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

This formula may be expressed quantitatively as:

$$E = A F M + B F L + \frac{W}{C} + \frac{9.81 H M}{D}$$

where E = extra energy used for work (kj)

F = distance travelled (km)

M = liveweight (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 $(\frac{\text{work done}}{\text{energy used}})$

D = efficiency of raising body weight $(\frac{\text{work done raising body weight}}{\text{energy used}})$

Quantities F, M, L, W and H can all be determined routinely. The two weights M and L present no problem and F and W can be measured throughout the working day using apparatus developed at CTVM (Lawrence and Pearson 1985). The distance moved upwards, H, may be estimated from a knowledge of the animals' itinerary and a good large-scale map.

Factors A, B, C and D have all been investigated intensively at CTVM and elsewhere and the results are summarised in Table 2. Table 3 shows the application of this formula using appropriate values of A, B, C and D to 2 days work done by a 620 kg ox.

The heat increment associated with work should be the same as that for maintenance since, in both cases, it is produced mainly as a result of converting the ME in the diet to the correct form for fuelling muscle tissue, albeit at a much greater rate in the working than the non-working animal. Some support for this supposition came from a study at CTVM in which two Brahman cattle performed a standard amount of work both at maintenance level of feeding and after a 48-hour fast. In both cases, the energy used to do the work was almost the same. Had the use of dietary ME for work involved any metabolic activity over and above that required for its use for maintenance, then the animals would have used more energy to do the work at maintenance than when they were starving.

It is practically very difficult to do this kind of experiment since the animals were, not suprisingly, reluctant to work after a prolonged fast. Furthermore, short experiments of this type do not preclude the possibility that prolonged work throughout the day may result in an overall increase in basal metabolic rate during rest periods. In order to clarify the situation, experiments need to be done in which the energy expenditure of animals is mea-

Table 2. Values for factors used to calculate the extra energy consumption of draught animals for work.

Factor and units	Numerical value ± S.E.	Number of observations	Type of animal	Author(s)	Comments
A Joules per kg live-weight per m travelled	2.09 ± 0.062	61	Brahman cattle and swamp water buffalo	Lawrence and Stibbards (1985)	Walking speed range 0.4 – 1.6 m/sec
”	2.0		Cattle	A.R.C. (1980)	Preferred value derived from several authors
B Joules per kg carried per m travelled	4.24 ± 0.24	24	Buffalo	Lawrence and Stibbards (1985)	Load placed in saddle on the middle of the animal's back
”	2.60 ± 0.19	24	Brahman cattle	”	Load placed in saddle over the animal's shoulders
C Ratio work done pulling/ energy used	0.389 ± 0.010	30	Buffalo	Lawrence (1985)	Most data for animals in single harness wearing collars
”	0.298 ± 0.0006	80	Brahman cattle	”	Data for animals in double and single yokes + a few for single animals with collars
D Ratio work done raising body wt/ energy used	0.356 ± 0.011	24	Brahman and Brahman × Friesian cattle	Thomas and Pearson (1985)	Results taken at ambient temperatures of 15 and 33 °C
”	0.35		Cattle	A.R.C. (1980)	Preferred value derived from two authors

sured for 24 hours both while at rest and when doing a normal day's work.

Energy Required for Work and its Provision

Work carried out at the Escuela Centroamericana de Ganaderia in Costa Rica shows that the extra energy used by oxen during a normal working day is not large. Table 4 shows the daily energy expenditure calculated in the manner previously described and expressed as a multiple of maintenance of six oxen on different diets and under different conditions of management. Even under optimum conditions of feeding and management, the oxen only used energy equivalent to 1.67 × maintenance when working a 5.5-hour day.

Theoretical calculations for beef and dairy cattle producing at rates typical of developing countries show that draught animals generally need less energy than dairy cows of similar size and the difference becomes even greater when it is considered that oxen seldom work every day in a week and maybe only 100–200 days a year.

In practice, the main constraint to providing this energy when only poor quality food is available in the voluntary dry matter intake (VDMI) of the animal. Another part of the Costa Rican study (Table 5) showed that on a diet consisting of 22 g of concentrate/$kg^{0.75}$/day plus very poor quality hay ad lib the average VDMI of six oxen was virtually the same during weeks when they worked as when they were idle. On a poorer diet (11 g concentrate/ $kg^{0.75}$/day plus hay ad lib) work was associated with a slight decrease in VDMI. These results also illustrate another important point which is that tropical forages are often of too poor a quality to supply maintenance let alone the extra energy re-

Table 3. Estimates of the energy expenditure (E) of 620-kg ox made using the formula

$$E = A F M + B F L + \frac{W}{C} + \frac{9.81 H M}{D}$$

where F = distance travelled (km)
M = liveweight (kg)
L = load carried (kg)
W = work done whilst pulling (kJ)
H = distance moved vertically upwards (km)

A, B, C and D are empirical factors listed in Table 2. The values chosen for this table were:
A = 2.0 J/kg/m
B = 2.6 J/kg/m
C = 0.30
D = 0.35

Job	Ploughing medium soil	Pulling 500 kg cart on tarmac road
Time spent working (h)	5.5	5.5
Distance travelled (km)	11.59	19.52
Work done (kJ)	6400	1955
Average load carried* (kg)	10.7	1.9
Distance raised (km)	0.030	0.310
Energy used for walking (kJ)	14372	24205
Energy used for carrying (kJ)	322	96
Energy used for doing work (kJ)	21333	6517
Energy used for raising body weight (kg)	521	5387
Total energy used (kJ)	36548	36205
Energy used for walking (%)	39.3	66.9
Energy used for carrying (%)	0.9	0.3
Energy used for doing work (%)	58.4	18.0
Energy used for raising body weight (%)	1.4	14.8

* Vertical component of load.

quired for work. In this case, although the animals worked on average only one day in three, they only just maintained body weight on the better diet and made substantial average losses on the poorer one.

If therefore an animal at or near maintenance and feeding to appetite is required to work then the extra energy for work must be supplied by increasing the quality of the diet, i.e. by giving a concen-

Table 4. Energy expenditure expressed as a multiple of maintenance (± S.D. where applicable) of various types of cattle.

Type of animal	Energy expenditure
6 working oxen, diet 1, management 1	1.42 ± 0.10 (n = 50)
6 working oxen, diet 2, management 1	1.51 ± 0.08 (n = 60)
6 working oxen, diet 3, management 2	1.67 ± 0.18 (n = 90)
Beef steer* 500 kg gaining 0.25 kg/day	1.18
Beef steer* 500 kg gaining 0.75 kg/day	1.67
Dairy cow* 500 kg milk yield 5 l/day	1.50
Dairy cow* 500 kg milk yield 10 l/day	1.98

* Theoretical calculation
diet 1 = 11 g/kg$^{0.75}$/day concentrate + poor hay ad lib
diet 2 = 22 g/kg$^{0.75}$/day concentrate + poor hay ad lib
diet 3 = medium quality pasture ad lib

management 1 = general farm work, 5.5 h/day, all setting up and adjustments to implements included. Animals worked 5 days consecutively at a time.

management 2 = animals worked continuously and as hard as humanely possible for 5.5 h/day all setting and adjustments to implements excluded. Animals never worked more than one day at a time.

Table 5. Voluntary dry matter intake (VDMI) of six oxen fed two different diets when working and resting.

	Diet 1	Diet 2
Average VDMI during resting weeks (kg/day)	8.3 (n = 30)	9.8 (n = 14)
Average VDMI during working weeks (kg/day)	8.1 (n = 10)	10.0 (n = 12)
Average change in liveweight (kg/animal)	-19	+1

Notes:

1. Diet 1 = 11 g concentrate/kg$^{0.75}$/day + poor hay ad lib.
2. Diet 2 = 22 g concentrate/kg$^{0.75}$/day + poor hay ad lib.
3. n = number of weeks during which measurements were taken.
4. Changes in liveweight occurred during 8 weeks on diet 1 and during 6 weeks on diet 2.
5. Liveweights of oxen ranged from 680–385 kg.

trate supplement. In poorer countries this may mean that draught animals then become direct competitors for food with human beings.

Conclusions

From the previous sections it can be seen that the strategy for draught animal use in a particular area may well depend largely on the amount and type of food available.

In places blessed with grass containing more than about 9 MJ of ME/kg dry matter, the feeding of draught oxen should be no problem since food of this quality will allow an animal to work at what appears to be the optimum level of energy expenditure (1.7 × maintenance) during most of the week without losing body weight. Supplementary feed would only be needed for such animals if they are also expected to perform some other function such as producing meat or milk.

If grazing is plentiful but of poor quality, it is probably better to have more animals doing what little work they can rather than to have fewer animals attempting to do more work than the quality of the food permits. Other advantages to be gained from having larger numbers of animals is that the farmer is protected to some extent against the consequences of accidental loss or injury of animals. He can also afford to use animals in pairs which provides greater maximum draught force for heavy jobs and facilitates the training of young animals that can be teamed up with more experienced ones.

In cases where land is scarce and/or grazing is very seasonal the appropriate strategy is to use fewer animals and to get as much work out of each of them as possible. Thus, although some of the farmer's time and land are used merely to grow forage or concentrates for oxen so that they can support the higher work levels, the amounts required are kept to a minimum. An alternative to growing crops exclusively for oxen is to grow a cash crop which has some by-product which the animals can eat, e.g. the tops of sugar cane.

In all the cases considered, it is possible to estimate total food requirements using the ME system as follows: (a) estimate the total amount and type of work which needs to be done, (b) calculate the ME necessary to do the work, (c) decide on the basis of the quality of food available how many animals are needed to do the work, and (d) calculate total food requirements for maintenance and work. Providing the food available provides a balanced diet for maintenance and sufficient extra energy for the level of work required, then the nutritional needs of the animal should be satisfied.

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Nutrition of Draught Animals with Special Reference to Indonesia

A. Bamualim* and Kartiarso**

In Asia, various animals are used for draught; however the relative importance of different species varies from region to region. Buffaloes and cattle are recognised as the major sources of draught power for food crop production in Asia, whereas horses are used to a lesser extent (Smith 1981). Although the mechanisation of agriculture in rural areas of many developing countries is frequently recommended, it is not often accepted by the farmers due to lack of capital, skill, spare parts, and oil prices. Considering the farm size and economic conditions of the majority of farmers in the tropics, it is likely that draught animals will play an important role in agriculture for the foreseeable future.

From China to south of the Sahara in Africa, the use of animals for draught purposes is of great importance. In India, it was estimated that about 80 million animals were used for draught and contributed about 32% of total energy presently being used in agriculture (Srivastava 1984). In Bangladesh, there are about 11.5 million cattle available for draught (Hussein 1981) and in Indonesia, Rollinson and Nell (1973) estimated that 5.3 million cattle and buffaloes, or 58% of total numbers of cattle and buffaloes, were used for work. For the last 10 years, Indonesia has been able to double its rice production from less than 10 million tons to 25 million tons in 1984, due to the introduction of high yield rice varieties; the increase in rice production was made possible by the contribution of cattle and buffaloes which provide the draught power for rice cultivation.

The primary reason for the farmer in Indonesia to keep cattle and buffaloes was in fact for agricultural work, particularly in areas of Java (Rollinson and Nell 1973; Petheram et al. 1982) where cattle and buffaloes comprised the largest proportion of total numbers of draught animals. Although Java is only 7% of the total land area, it contains over 70% of the human population and 60% of the ruminant population of Indonesia. Increasing competition for land use, due to population pressure on Java, decreases justification of the use of agricultural land for animal production under grazing systems which are limited to road verges, open fields, and unused lands between forest and cultivated land. Under such situations, the fibrous feed residues such as rice straw, other agricultural by-products and field grasses have therefore become important feed resources for draught animals, which are usually stall-fed using the cut-and-carry system.

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Factors Affecting Nutrient Requirements of Working Animals

The major factors affecting nutrient demands of ruminants are the different physiological states, i.e. maintenance, growth, pregnancy, lactation, and work. With the majority of cattle and buffaloes starting to work at least by 2 years of age or at about 200 kg liveweight, it is appropriate to consider the different physiological states from 2 years of age.

For working animals, the effects of physiological states on nutrient requirements may conveniently be considered in two main phases, at maintenance and at production states (growth, pregnancy, and lactation) which are briefly discussed in the following section.

Maintenance and Production

Feed that is consumed and digested by cattle and buffaloes is converted to meat, fat, milk and work power, but in the first place it is necessary that the animal receive sufficient nutrients for its own maintenance. This can often be met by using diets containing a high proportion of roughage and other low-quality feeds. The energy requirement for work is influenced by several factors such as the intensity and duration of the work, the environmental and physical conditions in which the work is performed, and the condition and body weight of animals. In general, working animals will require an extra amount of energy for muscular work above that required for maintenance only.

With regard to the productive state, late growth animals (⩾ 2 years old), pregnant animals particularly up to two-thirds of the pregnancy period, and lactating animals are frequently used for draught in villages. The use of productive animals for work imposes an additional stress on the animal's nutrient requirements especially when the quantity and quality of feed available is restricted.

Nutrient Requirements of Draught Animals

Traditionally, the nutrient demand of any animal has been computed as the nutrient requirements for maintenance alone or with additional requirements for production as published by NRC (1978) or ARC (MAFF 1975). With the exception of horses, data on the nutrient requirements of working animals are extremely limited and not well documented. Although estimations on the nutrient demands of cattle and buffaloes for work have been made (see Table 2) (Ranjhan and Pathak 1979; Kearl 1982; Mathers 1983), further studies are required to develop basic nutrient requirements for working animals doing particular tasks. The relative priorities of groups of nutrients were given by Preston and Leng (1984) according to the physiological and biochemical processes in ruminants. They argued that mature draught animals have a specific need for oxidation energy with minimum need for both glucogenic compounds and amino acids.

Energy

The prime need in feeding draught animals is to supply sufficient energy during working periods. The energy requirement of cattle and buffaloes for maintenance is increased with increasing body weight and with the amount of work that is involved (Table 1).

In general, work can double the energy requirements of the cattle depending on the extent of work. Buffaloes are more efficient than cattle in utilising energy for work (Lawrence, cited by Mathers 1983). It was estimated that the mean energy costs of pulling loads, over the cost of walking, were 26 and 33 J/kg pulled/metre for swamp buffaloes and Brahman cattle respectively. For similar kinds of work, buffaloes will therefore require relatively less energy than cattle (Table 2). Lawrence (cited by Mathers 1983) suggested that the buffaloes may be able to divert some of the energy for walking into power for pulling.

The extent of energy demands for growing and lactating animals under non-working or working conditions is shown in Table 2. It seems unlikely that growth or lactation can be fully supported by high roughage diets during working periods, unless good quality forages such as cassava leaves, sweet potato leaves, leucaena leaves or concentrate feeds are also to be included in the diets.

Studies with horses indicated that the intake and digestibility of a low protein diet was increased by work (Orton et al. 1984), which may also be true for cattle and buffaloes. Although the energy intakes were increased, maximum intakes are likely to be restrained when feeding high roughage diets. Mathers (1983) estimated that the metabolisable energy (ME) intakes of a 300 kg steer fed high roughage diets can only be increased up to 40% above that required for maintenance. If an animal needs for work an extra 80% of ME above mainten-

Table 1. Energy requirement by cattle and buffaloes for maintenance and percentage extra energy requirement for work (modified from Kearly 1982).

Energy requirement	Body weight (kg)			
	200	300	400	500
Cattle*				
Maintenance (MJ ME/day)	27	37	46	54
Extra energy requirements above maintenance (%):				
2 hours work	18	20	22	23
4 hours work	37	41	44	47
8 hours work	74	82	88	94
Buffaloes**				
Maintenance (MJ ME/day)	28	38	47	55
Extra energy requirements above maintenance (%):				
2 hours work	14	16	17	18
4 hours work	29	32	34	36
8 hours work	58	64	69	73

* Assuming cattle used for ploughing produce 75% as much power as horses (PCARR 1978) at the slow trot which need 16.7 KJ/kg body weight of horse/hour (NRC 1978).

** Buffaloes are 1.25 times more efficient than cattle in pulling loads (Mathers 1983), therefore buffaloes need less energy than cattle for agricultural work. Values in the table are comparable with Ranjhan and Pathak (1979).

Table 2. Estimation of energy requirements by a 200-kg growing heifer (gain 0.25 kg/d) and a 300-kg lactating cow (5 kg milk/d) under non-working and working conditions.

	Growth	Lactation
Maintenance (MJ ME/d)	27	37
Energy requirements for production (% above maintenance):		
No work	29	64
Work 4 hours/day	65	106

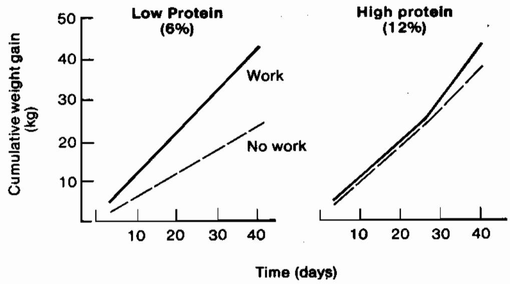

Fig. 1. Effect of work on growth of horses fed low and high protein diets (adapted from Leng 1983, Orton et al. 1984).

ance, there will be an energy deficit which may result in a small body weight loss of about 0.3 kg/day. Body weight loss is quite acceptable by the farmers during working periods, but when weight loss appears to be excessive, the workloads must either be decreased or additional high-energy feeds be given (Starkey 1984).

Protein

With very heavy work, the protein requirement of the animal may be increased up to 180% (Leng 1983), through the catabolism of tissue protein to supply energy. However, with light-medium work, there is no evidence at the present time that work increases the protein requirement above maintenance levels. Webster and Wilson (1980) suggested that an additional 13.5 g of digestible protein is required for each hour worked by cattle; this amount of protein could be sufficiently provided through the possible increased feed intake caused by work.

Work increased feed intake of horses on 6% protein diet and the animals grew at the same rate as horses on 12% protein diet (Fig. 1). Probably, as work increased the intake of low protein diet, the supply of protein was increased to a point somewhere above minimum requirement for growth which resulted in similar growth rates to those on a high protein diet. Furthermore, because the energy is dissipated in work, a better balance of protein/energy ratio (P/E) in the nutrients available to the animals was achieved. This may have similar implications for cattle and buffaloes, and research is currently in progress using buffaloes at the Research Institute of Animal Production-Bogor to examine this hypothesis.

If similar feed intake and conversion responses occur in working cattle and buffaloes, then protein requirements are likely to be met by this response in low-medium productive animals; however, supplementation would be required for high productivity and/or diets that are very low in protein.

Minerals

The essential dietary minerals should be supplied in adequate quantities to meet the animal's requirement for normal metabolism. There was insufficient information to indicate that mineral requirements increase above maintenance levels for work, except for salt. Losses of some minerals, particularly NaCl, are associated with sweat during work. It was estimated that from 90 g NaCl excreted daily, 50–60 g was excreted in the form of sweat from a horse during haulage for 50 km (Leng 1983). After working, salt can be economically provided by farmers to supplement the animal feed.

Table 3. Estimation of nutrients supply and demand for a 290-kg buffalo fed rice straw or rice straw + grasses during non-working and working periods.

	Rice straw (kg DM/d)	Field grasses (kg DM/d)	Energy (MJ ME/d)	Protein (g/d)
Not working				
Intake*	8.0	-	42.3**	350**
Requirement for maintenance			37.0	370
Work 4 hours/day				
Intake***	6.0	2.0	44.5	530
Requirement for maintenance + work			47.0	370

* Mean intake of six buffaloes fed rice straw measured in the village at Bogor.
** Rice straw contained 14.5 MJ/kg DM and 4.4% protein. The ME value was calculated based on 45% DM digestibility.
*** Assuming the animals had similar intake as when not in work, and consumed 25% of the diet as grasses eaten during grazing after work. The grasses contained 15.5 MJ/kg DM and 13.5% protein and DM digestibility of 50%.

Feed Supply and Demand for Draught Animals

In the Indonesian situation, field grasses and rice straw are the cheapest source of nutrients for draught cattle and buffaloes. The proportions of grasses or straw given to the animals vary with area and season. Estimation of the potential for such forages to satisfy the nutrient requirements of working cattle and buffaloes is given below after briefly describing the feeding practices in Indonesia.

Feeding Practices

Draught cattle and buffaloes are most prevalent in rice plantation areas. Most animals are tied around households and fed rice straw or green grasses collected from uncultivated areas. During dry season, after rice and other crops have been harvested, cattle and buffaloes are herded on rice fields or on communal grazing lands where they graze the rice straw, other crop by-products, or grasses. From the start of, and throughout, the wet season, when rice fields are being cultivated, grazing areas are scarce. At this time, cattle and buffaloes are commonly used for work on an average of 4 hours daily and are allowed to graze after working for a few hours on marginal lands. Better animal condition may be observed during the breeding period which is from late wet season following post-harvest time until the middle of the dry season, since during this period increased areas are available for grazing. Feeding management of buffaloes in wet and dry seasons was derived from a survey of four villages in the lowland area in West Java (Petheram et al. 1982). The pattern of feeding from grazing was 50% in the dry season and 80% in the wet; pen feeding was 50% and 20% respectively. The pattern of feeding may also vary from one region to the other. There are some high rainfall areas in West Java (i.e. Ciawi) where seasons do not have much effect on the feeding system or on the work pattern of cattle and buffaloes. On the other hand, in northern and eastern parts of Java seasonal effect on the feeding habits of draught animals is more pronounced than in West Java.

Ability of Feeds to Satisfy Nutrient Demands

The potential for a forage to meet the nutrient demands of draught animals may be calculated from data on the amount of feed consumed, feed digested and the nutrient requirements. An assessment of the ability of rice straw and field grasses to satisfy the buffaloes' nutrient demands was made under village condition at Bogor area as shown in Table 3.

The energy supply may be slightly less than that required for maintenance + work, but the extra protein supply above the maintenance + work requirement can become a source of energy to cover the energy deficit. Therefore, during working periods, the animals can possibly be maintained by feeding fresh rice straw in their stall and by allowing them to graze grasses grown on the rice dikes or available marginal grazing lands.

Energy supply is slightly in excess of requirements when the buffaloes were not working (Table 3). However, unless the intake can be further increased or supplementation with protein sources is given, only very small body weight gains may be expected. Under the cut-and-carry system in the village, one of the limitations is that the amounts of feed offered are sometimes much less than the intake potential of animals.

It is clear that feeding fresh rice straw alone cannot sustain productive draught animals. Supplementary feeds which can be fed in the stall to supplement rice straw or field grasses should be considered for these animals. The inclusion of 25% leucaena or cassava leaves in the rice straw basal diet could produce a daily gain of more than 200 g, when the buffaloes are not in work (calculated from MAFF 1975). Much higher gains may be expected when field grasses are also used to replace some of the rice straw.

Possible Research Areas

In spite of the importance of cattle and buffaloes as draught animals for crop cultivation, very little information is available on the problems encountered when these animals are used for work, and their productivity is largely unknown. Although the government of Indonesia has paid substantial attention to draught animals in their role of helping the small farmers, i.e. through a scheme to lend pairs of draught cattle and buffaloes to small farmers, there is no major research program on draught animals.

We feel the following areas need further study:

- An assessment of the present and future situation of draught animals in Indonesia; initial surveys and monitoring of the productivity of these animals should be undertaken in different representative areas. This may serve as a basis from which to determine further research priorities.
- An assessment of nutrient requirements and feed availability for draught animals should be made.
- Reproductive aspects, in particular when the females are used as draught animals, should be studied.

- Comparisons of working capacity of cattle and buffaloes to determine their energy efficiency compared to mechanical power.
- The use of correct harness and equipment to increase the work potential should be investigated.

Conclusion

Draught animals are extremely important in the agricultural systems of developing countries. Data available on the nutrition of draught animals are scarce; lack of knowledge particularly on protein demands suggests that more research is needed in this area. Rice straw and field grasses may be sufficient to maintain cattle and buffaloes during working periods, but such diets cannot effectively meet the nutrient requirements of productive animals. The use of supplement with high quality forages is suggested when productive animals are used for work.

It is difficult to suggest the research priorities of draught cattle and buffaloes at this stage before initial surveys and monitoring studies on the relative productivities of these animals have been undertaken first. However, it is foreseeable that the nutrient requirements of these ruminants need to be measured directly according to the type of work that is being undertaken.

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Muscle Metabolism and Nutrition in Working Ruminants

R. A. Leng*

MECHANICAL work, transport of ions across membranes and tissue synthesis probably use most of the high-energy phosphate bonds generated in oxidative metabolism in mature animals. A mature animal at rest expends most of its energy to support basal metabolism but a draught animal working at a steady rate, say ploughing, uses nutrients for energy (i.e. ATP) at six to ten times the rate at rest.

Digestion and Metabolism in Ruminants

The source of all potential energy for muscular work is the absorbed products of digestion of the feed. The digestion of feed and metabolism of the absorbed nutrients in ruminants have been reviewed and comprehensive information is now available on the nutrients available for metabolism (see Leng 1982).

Draught animals in developing countries are largely supported on crop residues. These may be supplemented with by-products of agroindustries, or by grazing communal lands and/or with grass cut from roadsides. The draught animal is fed, in general, the least nutritious feed resources; the 'better quality' feeds are retained for the 'more productive' females and/or young animals.

The majority of draught animals are probably fed on straw, which is inefficiently digested since it is deficient in fermentable-N to support rumen function. During periods of no work, intake of straw is between 1.8–2% of body weight, but digestibility is only 40%. The intake and digestibility of straw is increased by feeding urea. The data in Table 1 summarise the calculated amounts of substrates available for metabolism and utilisation in an animal on straw or straw supplemented with urea.

Volatile fatty acids (VFA) are absorbed mainly from the forestomach of the ruminant. In the gut epithelial cells and/or liver almost all the butyrate is converted to ketone bodies (Leng and West 1969) and all the propionate to glucose (Leng et al. 1967; Cridland 1984) but acetate is absorbed unchanged. Most of the amino acids from microbial and dietary protein digested in, and absorbed from, the small intestine are metabolised (largely in the liver) in the adult working animal, since it is in either zero or negative N balance. Absorbed amino acids therefore supply a considerable proportion of the metabolisable energy available to a mature working animal at maintenance (see Table 1). Amino acids are catabolised in the liver to acetate, ketone bodies and glucose. Dietary long chain fatty acids enter the blood directly by absorption from the intestines.

The circulating substrates that are available for muscle metabolism are therefore acetate, ketone bodies, long chain fatty acids and glucose.

Additional sources of potential energy for muscular work include the triacylglycerol (fat) of adipose tissue and the glycogen and fat present in all tissues of the body. Resting muscle has reserves of triacylglycerol and glycogen which can be oxidised directly to supply ATP for contraction.

Effects of Work on Energy Expenditure

To place in perspective the effect of work on energy demand the metabolic rates of draught animals have been calculated at rest, and carrying out light or heavy work.

Skeletal muscle represents some 25% of the body mass of ruminants and probably considerably more than this in the working animal. Although resting muscle has a low metabolic rate, Vernon (1970) suggests that muscular activity in heavily working animals can account for up to 90% of the oxygen consumption of the animal.

The effects of heavy work on energy expenditure in mature working animals (i.e. 6 hours ploughing a day) as compared to light work (6 hours walking) is shown in Table 2. The total daily (i.e. 24 hour) energy expenditure of a tethered animal is 1.5 times higher than its basal energy expenditure; an animal

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Table 1. Calculated availability of metabolisable nutrients from fermentative digestion in the rumen of an oxen (500 kg liveweight) consuming 10 kg of straw without supplementation (diet A) or supplemented with urea/minerals (diet B). It is assumed that in the unsupplemented animal the digestibility of straw in the rumen is 40% and the efficiency of microbial growth is low (i.e. Y-ATP = 8) and that supplementation with urea/minerals increases digestibility to 50% and the microbial growth yield (Y-ATP) to 14 (see Leng 1982).

	Diet A	Diet B
Digestible straw intake (kg)	4	7
(MJ)	70	123
*VFA produced (MJ)		
(a) Acetic	22	34
(b) Propionic	11	16
(c) Butyric	8	11
Energy losses in fermentation (MJ)		
Methane	9	15
Heat	6	9
(d) ** Dietary long chain fatty acids (MJ)	4	6
(e) * Microbial cells produced (kg)	0.83	2.3
(f) *** Digestible microbial cells (kg)	0.66	1.9
(MJ)	11	31
(g) Energy available for metabolism		
(a + b + c + d + f) (MJ)	48	98

Assumptions

* That the stoiciometric relationships of VFA production and microbial cell growth is the same as that discussed by Leng (1982).
** Straw contains 1% digestible fat.
*** Digestibility of microbial cells is 80%.

Table 2. Calculation of the effects of various activities on energy expenditure of mature draught animals.

Activity	Sleeping/ lounging (1)*	Eating/ ruminating (2)*	Light work (3)*	Heavy work (10)*	Total hourly equivalent of BMR	Multiples of BMR**
Non-working						
(a) Time spent on activities (hr)	12	11	1	0		
(b) Hourly equivalents of BMR	12	22	3	0	37	1.5
Walking (6 hr)						
(a) Time spent on activities (hr)	6	11	7	0		
(b) Hourly equivalents of BMR	6	22	21	0	49	2.0
Ploughing (6 hr)						
(a) Time spent on activities (hr)	6	11	1	6		
(b) Hourly equivalents of BMR	6	22	3	60	91	3.8

* Figures in brackets are the energy cost of the activity relative to basal metabolism.
** In this calculation the hourly equivalents of BMR for a day is 24.

walking with a companion, that is ploughing, increases by 2.0 times its basal metabolism whereas the animal ploughing increases its daily energy expenditure by 3.8 times its basal metabolic rate, illustrating the enormous effect of work.

Mechanisms of Muscle Contraction

Muscles contract to work through interactions among thick and thin protein filaments that make up muscle fibres. Striated muscle fibre consists of several thousand myofibrils. The detailed structure and physiology of contraction are well described by Huxley (1976) and McGilvery and Goldstein (1983).

Substrate For Exercising Muscle

In the following discussion the trends between resting and exercising muscles, and levels of light exercise are presumed to indicate the most likely substrates for the heavily working muscle. No studies have been reported with cattle or sheep under heavy and continuous workloads.

The important substrates supplied in blood to skeletal muscle include acetate, ketone bodies, long chain fatty acids (LCFA) and glucose. Amino acids also represent a potential but minor source of energy.

The substrates that can be mobilised for oxidation in skeletal muscle include glycogen and triacylglycerol (fat). Amino acids from muscle protein may be mobilised but they are unlikely to be significant.

The technique combining A-V differences with isotope dilution technology has provided considerable information on the substrates used by skeletal muscle (isolated hind limb) of both sheep and cattle (see Annison 1984).

Uptake of acetate is low but related linearly to its arterial blood concentration in the hind limb of sheep and cattle (Bell 1980).

The rates of utilisation and oxidation of the long-chain fatty acids, stearic, palmitic and oleic acids were also linearly related to arterial concentrations in the blood supplying skeletal muscle in the pregnant ewe (Pethick et al. 1983).

Ketone body uptake by the hind limb of sheep and cattle (Jarrett et al. 1976) is higher than in nonruminants and again directly related to arterial concentrations over a range of normal blood values (Bell 1980) but is severely limited at levels above 3–4 mM (Pethick and Lindsay 1982b).

Glucose oxidation (excluding glucose C. released as lactate) appears to make a significant contribution to substrates used for ATP synthesis in muscles. In fed ewes, 26% of glucose uptake is promptly oxidised by hind limb muscle and accounts for 17% of the oxygen uptake (see Pethick 1984). Recently in a comprehensive study of glucose utilisation in sheep Oddy et al. (1985) measured the proportion of the glucose synthesised that was utilised by muscle, uterus and mammary gland. The amount of glucose used by muscle was remarkably similar irrespective of the demand for glucose by the pregnant uterus or mammary gland (see Fig. 1).

Endogenous substrates (largely glycogen and fat) provide a mobilisable fuel resource for combating periods of substrate shortage during heavy work. Endogenous substrates may be quickly exhausted in working muscles; they are, however, replenished during periods of rest, probably from circulating free fatty acids and glucose.

The conclusions are: (1) that the contribution of various substrates to energy required for muscle in non-exercising sheep is related to the arterial concentrations of substrates; (2) nutritional and physiological state affects the circulating levels of blood metabolites and therefore the contribution of individual substrates to muscle metabolism; and (3) acetate and glucose appear to be significant substrates for the resting skeletal muscle, with lesser roles for ketone bodies and free fatty acids in sheep in a number of fed and fasted states (Table 3).

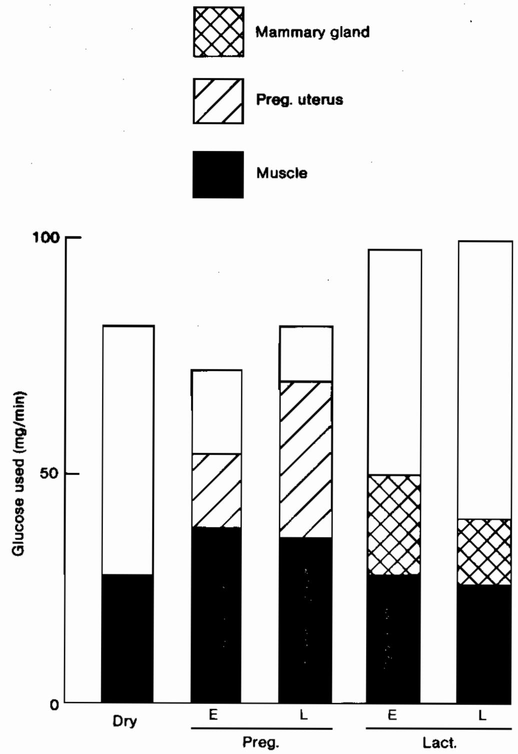

Fig. 1. The amount of glucose used by skeletal muscle, pregnant uterus and lactating mammary gland relative to the glucose irreversible loss rate (synonymous on this diet of lucerne to net glucose synthesis rate) in normal dry sheep or sheep in early pregnancy (E), late pregnancy (L) and early lactation (E) and late lactation (L). The sheep were fed chopped lucerne chaff (Oddy et al. 1985).

Exercise and Substrate Utilisation in Muscle

Bird et al. (1981), in a comprehensive study of substrate utilisation in the hind limb of sheep, resting or walking on a treadmill, clearly showed the changes that occurred in substrate utilisation. Exercise increased oxygen uptake by the hind limb 6–7 fold. This was closely related to an increase in blood flow rate to the muscle. The arterial blood also increased its oxygen-carrying capacity due mainly to an increased red blood cell concentration and there was also an increased affinity of the cells for oxygen.

Table 3. Arterial concentrations (A-c, mM) of metabolites and their apparent contribution to oxygen uptake (%O_2) by skeletal muscles of the hind limb of sheep in various physiological conditions (collated by Pethick et al. 1984; Pethick and Lindsay 1982a).

	Fed sheep		Starved sheep (6d)		Fed-pregnant sheep		Starved pregnant sheep		Lactating-fed sheep	
Substrate	A-c	%O_2	A-c	%O_2	A-c	%O_2	A-c	%O_2	A-c	%O_2
LCFA	0.1	10	1.4	80	0.8	52	1.6	91	n.a.	n.a.
Ketone bodies	0.4	15	1.2	36	1.0	19	3.2	48	0.4	16
Acetate	1.2	35	0.1	<1	1.2	34	0.2	<1	1.2–2.4	22–36
Glucose	2.9–3.8	44	2.3	0	2.5	35	1.4	10	3.0	32

Table 4. The maximum contribution of circulating and endogenous metabolites to oxidation in skeletal muscle of the hind limb of fed sheep during sustained exercise (collated by Pethick 1984).

	Duration of exercise		
Metabolite	15 min	60 min	120 min
Acetate	8	8	8
Ketone bodies	2	4	4
Long chain fatty acids	15	26	40
Glucose*	21	25	29
Endogenous substrates in muscle	54	37	19

* Corrected for lactate uptake or output.

Walking for 60 min at 0.7 m/sec on a 10° slope resulted in increased blood concentrations of glucose, lactic acid and LCFA. The uptake of LCFA and glucose by muscle increased but LCFA oxidation accounted for most of the oxygen uptake of muscle (see Fig. 2).

Pethick (1984) summarised the available data on the effects of exercise (Table 4). These data supported his own work which showed an increase in long chain fatty acid utilisation as the work period progressed (Table 5).

Table 5. The potential availability of glucogenic energy to draught oxen fed 10 kg of straw (4 kg DOM) (A) and 14 kg straw when supplemented with urea (7 kg DOM) (B).

	Diet A	Diet B	Potential glucose availability (A)	Potential glucose availability (B)
Propionate absorbed (moles)	10.7	10.8	963	972
Amino acids absorbed* (g)	400	1140	220	627

* Assumption that of the digestible microbial protein 55 g glucose are potentially available per 100 g amino acids metabolised (Krebs 1964).

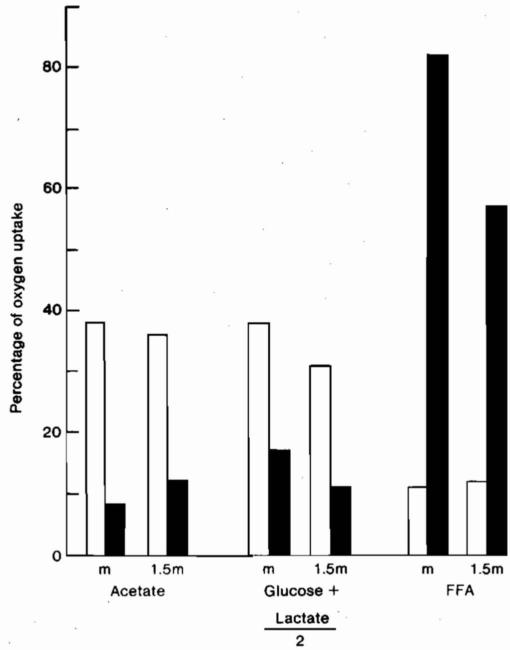

Fig. 2. Substrate utilisation in resting (open blocks) or working hind limb muscle (filled blocks). The histograms represent the proportions of the oxygen uptake attributable to acetate, glucose or long chain fatty acids (Bird et al. 1981). The sheep were fed at maintenance (m) or one and a half maintenance (1.5m).

The uptake of glucose by muscle is intriguing because of the concept of glucose being in limited availability in productive ruminants particularly where they are fed crop residues (Preston and Leng 1984). An increased requirement for glucose may therefore be an important constraint to work, particularly if growing animals or productive females are to be used for animal traction. For this reason glucose metabolism is discussed further.

Glucose Utilisation

Judson et al. (1976) found that in exercising sheep the amount of glucose passing through the glucose pool in the animal increased, and they attributed the increase to extra gluconeogenesis, however, recycling of glucose-C undoubtedly occurred to some extent (see Pethick 1984). Clearly glucose is a metabolite for muscle at rest and during work and long chain fatty acids become increasingly important with time (and with level of work?).

Glucose utilisation in muscle approximated 1.25 m mole/hr/kg muscle in fed, non-productive sheep but was approximately 0.3 m mole in the fasted pregnant sheep (see Pethick 1984). Glucose uptake by muscle increased with exercise (walking at 5 km/hr) as did the uptake of FFA (see Fig. 3) (from Pethick and Chong 1985). If the muscle mass in a 40 kg sheep is about 25% of body weight (i.e. 10 kg) then muscle accounts for the utilisation of 37.5 mg glucose per min (4.5 g/2 hr) at rest in a fed animal, 6 mg/min (0.72 g/2 hr) in a fasted pregnant animal but as much as 105 mg/min (12.6 g/ 2 hr) in a sheep walking on a treadmill at 5 km/hr. In these physiological states glucose passing through the body pool varies from 30–100 mg/min (see Leng 1970) and therefore the muscle when working uses a high proportion of the glucose normally available and the animal must be mobilising glucose from its glycogen reserves. As the liver contains about 5 g glycogen/100 g and the skeletal muscle 1–2 g glycogen/100 g these reserves could be potential sources of the glucose for muscle metabolism. The other sources are unused glucogenic potential from propionate and amino acids absorbed from the intestines and glycerol from mobilised fat.

Work would have increased glucose utilisation by only 6 g per day per hour of work (provided in the recovery period glucose utilisation was not increased). This approximates the hourly glucose entry rate measured in non-working animals and therefore if basal glucose utilisation is unaffected, it doubles the glucose requirements over the work

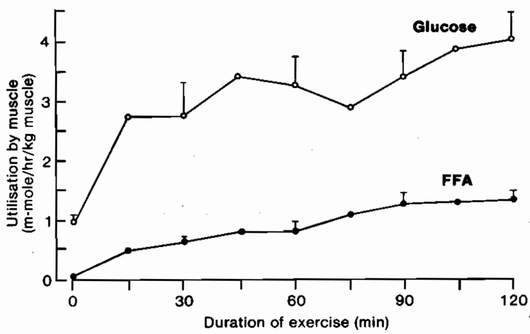

Fig. 3. Utilisation of long chain fatty acids and glucose in skeletal muscle of working sheep (Pethick 1984).

period. If work is of six hours duration then the overall glucose requirement might be increased by about 25% on a daily basis. This could be met by glycogen mobilisation during the work period or by increased gluconeogenesis. Glycogen recovery in liver or muscle would necessitate increased gluconeogenesis in the period following exercise. It is also possible that peripheral glucose utilisation is reduced in exercising animals conserving glucose for muscle metabolism in the same way as glucose may be conserved for use by the mammary gland and the pregnant uterus in lactating animals (see Annison and Linzell 1964; Setchell et al. 1972).

In pregnancy and lactation there is apparently a reduced utilisation of glucose by skeletal muscle. It is well established that the lactating mammary gland and the pregnant uterus use a high proportion of the available glucose in ruminants (Linzell 1967; Setchell et al. 1972) (see Fig. 1) and the hormonal balance of the animal therefore appears to conserve glucose for these purposes. A major conservation mechanism appears to be the incomplete oxidation of glucose to lactate in muscle as the carbon is recycled to glucose via the liver.

Sources of Glucose for Muscular Work

Because ruminants have a limited supply of glucose precursors (Leng 1970) it is unlikely that the workload of a draught animal is so heavy that the muscles use glucose extensively via anaerobic metabolism. From another viewpoint the work rate of the animals may be controlled below the point where glucose has to be used anaerobically by muscles. Glucose oxidation in muscle appears to be obligatory and the availability of glucose precursors from the digestive tract may be a critical constraint in the working productive female.

In a draught animal (500 kg liveweight) consuming 10 kg of straw (or 14 kg of straw when supplemented with urea), the available glucose precursors are largely propionate and digested microbial protein. The potential glucogenic potential in animals with and without supplementary urea is shown in Table 5.

The effect of adding urea to the diet is to increase the glucogenic potential of absorbed nutrients by about 30% or sufficient to meet the calculated need for 6 hours work.

In the mature animal at maintenance or the working animal that is not gaining weight, all the absorbed amino acids will be metabolised (largely in the liver) to give rise to acetate, ketone bodies or intermediates of glucose precursors. Roughly 55 g glucose may be synthesised from glucogenic amino acids from 100 g of digested protein (Krebs 1964).

Preferred Substrates of Skeletal Muscle

Conclusions concerning the substrates used by skeletal muscle rely on only a few publications dealing with the hind limb of sheep or cattle at rest or subjected to light to moderate exercise (1-2 hr walking on the flat or on a slight incline). No data are available on the substrates used in the muscles of working draught animals (i.e. 6 hours ploughing). The reports in the literature can therefore only indicate the substrate used in muscles under heavy workloads.

Besides the products of digestion and their metabolites (acetate, ketone bodies), the long chain fatty acids of dietary origin or mobilised from adipose tissue are the only substrates with sufficient pool size and potential to meet the substrate requirements for heavy work. Glucose oxidised in skeletal muscle over 6 hours may increase the daily glucose requirement by say 25% which can be readily obtained by using amino acids for glucose synthesis and from the increased nutrient availability that results from increasing feed intake (for example by feeding urea; see Table 1).

Nutrition, Work and Production

Ruminants throughout evolution have had to migrate over long distances, often working at a high rate to gather their food. They have been able to produce viable calves or lambs and sufficient milk to provide for adequate nutrition and growth of their offspring.

In traditional agricultural systems the male animal is kept for traction presumably because of its low demand for nutrients during seasons of no work (when the animal fattens) and its ability to mobilise body reserves during the work seasons. However, the draught animal in some countries competes for the available feed resources (even crop residues) with productive female animals which has resulted in Bangladesh in productive females replacing males as work animals (see Dolberg et al. 1981).

Development of knowledge of the supplementary nutrients required to balance crop residues for production has led to large increases in the productivity of ruminants fed these resources (see Preston and Leng 1984; 1985). If the increased productivity that has been achieved by rational supplementation of non-working animals could be applied to working animals, this would allow replacement of males with lactating/breeding animals. This would be a major breakthrough for increasing overall meat and milk production in developing countries.

Nutritional Constraints to Using Ruminants for Work

To be able to use a lactating or breeding cow for work, it is important that the work stimulates feed intake substantially and/or that nutrients, identified to be in critical supply, are provided in a supplement.

In most developing countries the primary constraint to feed intake of ruminants on cereal crop residues is usually the low fermentation rate in the rumen due to low rumen ammonia concentrations. Urea supplementation of straw-based diets leads to an increased intake (see Campling et al. 1962) and an increased fermentation rate in the rumen; microbial protein availability per unit of digestible food intake is increased and this results in a higher protein to energy ratio in the products of fermentative digestion (Table 1). The effects of work on intake of straw or straw/urea by adult working ruminants have not been reported but casual observations suggest feed intake is stimulated by at least 30%.

Nutrients for Work and Production

As workload increases, LCFA become increasingly important substrates for ATP generation in working muscle and possibly contribute 80-90% of the ATP (Bird et al. 1981).

Glucose oxidation appears to contribute a proportion of the energy for muscle contraction but this is only a relatively small proportion of that available. Even in heavily working animals glucose utilisation may only drain 25% of the available glucose. This may, however, be a significant drain when the requirements for glucose for milk production are highest. Protein or amino acids, however, do not appear to be utilised by muscles to any extent and acetate utilisation appears to be decreased and partitioned towards mammary utilisation (Pethick and Lindsay 1982a).

Thus in a working cow, glucose and long chain fatty acids are likely to be in high demand for work and milk production. Amino acids may be channelled into glucose if the requirement for glucose synthesis takes precedence over other metabolic functions.

Kronfeld (1982) suggests that the efficiency of milk production is highest when fat contributes 15% of the metabolisable energy intake. Approximately half the fat in milk of ruminants is synthesised from circulating long chain fatty acids, the rest for acetate, butyrate (and indirectly ketone bodies) (Linzell 1967). The in vivo synthesis of fatty acids in the mammary gland requires oxidation of glucose (to supply NADPH for fat synthesis) and glucose is also required for glycerol and lactose synthesis, therefore glucose requirements for lactation will be increased when the diet is low in fat. The availability of glucose is critical for milk output; Linzell (1967) demonstrated a linear relationship between glucose availability to the profused mammary gland and milk yield.

The above short discussion indicates that the requirements for glucose precursors and dietary long chain fatty acids would be increased enormously in a lactating cow that was forced to work particularly since crop residues are low in lipids (< 1%). Amino acid availability may not be a constraint because of the apparent lack of utilisation of amino acids by working muscle. However, this remains to be tested.

Future research therefore needs to address the study of working, lactating cattle fed crop residues by finding ways to provide extra glucose (as bypass starch— and long chain fatty acids (perhaps as supplements of insoluble calcium soaps because of the lack of effect of calcium soaps on rumen digestibility (see Palmquist 1984)).

It may not be just fortuitous that the kinds of supplement that may supply these critical nutrients (e.g. mixtures of rice bran, broken rice and oil seed meals) are those frequently used by smallholder farmers in developing countries.

Pregnancy

Pregnancy does not place a high demand on nutrients until the last month and provided animals can be rested towards term, work should be easily accommodated. The data of Lindsay et al. (1982) emphasise the likely supplements that would be beneficial on a straw-based diet (see Table 6). Because glucose provides the major energy nutrient for the growing foetus (Setchell et al. 1972) then in a working pregnant animal a source of glucogenic energy may be highly beneficial. This could be provided by increasing propionate production and/or supplementary feeding with bypass protein or starch.

Table 6. The effect of feeding urea/sulphur and bypass protein on the intake of hay (45% digestible, 0.4% N) and production of pregnant cattle (last 60 days) (Lindsay et al. 1982).

Supplement	Intake	Live weight change (kg/d)
None	4.2	-0.81
Urea/sulphur	6.2	-0.31
Urea/sulphur plus bypass protein (1 kg/d)	8.1	+0.75

Conclusions

Muscular contraction is accomplished largely through an interaction of the various protein elements that make up the thin and thick filaments of muscle fibres. Calcium released by nerve impulses activates the muscle proteins and ATP provides the energy. ATP concentrations in contracting muscle cells are maintained from a store of phosphocreatine. ATP generation occurs in mitochondria (which are closely associated with the bundles of filaments in muscle) from glucose, acetate, long-chain fatty acids or ketone bodies. Glucose appears to be unavoidably used to a small extent in both resting and working muscle. At first sight this appears to be disadvantageous because of the scarcity of glucose precursors and the essential requirement for glucose for a number of important functions. The utilisation of glucose under aerobic work conditions may be the price the ruminant has to pay to ensure the availability of glucose when oxygen requirement outstrips the ability of muscles to take up oxygen. Ruminants have evolved in an ecosystem where flight is their main defence and anaerobic glucose metabolism would have been essential in muscle tissues for survival. The well-developed enzyme systems for utilisation of glucose means that glucose metabolism depends on glucose availability which in turn depends on blood flow rate.

The availability of glucose for muscle metabolism in a draught animal is not likely to be a major constraint, but the need for glucose by the pregnant uterus and the lactating mammary gland may be the major constraint to using pregnant and lactating animals for work whilst maintaining production. With lactating animals the direct competition for long chain fatty acids (C_{16} and C_{18}) for milk synthesis and for metabolism in skeletal muscle may also create major difficulties.

Acetate appears to be preferentially partitioned towards metabolism in the mammary gland. As acetate oxidation in muscles is accompanied by more heat generation per mole ATP generated than other substrates, it seems that low acetate utilisation in working muscle is a sound metabolic strategy.

Knowledge of the substrates utilised by heavily working muscles is paramount for designing supplements to provide for the likely limitations to productivity of pregnant and lactating cows.

Feeding draught animals for work does not merely represent feeding for energy but feeding for specific nutrients to meet the substrates preferentially utilised by working skeletal muscles. These appear to be glucose and long chain fatty acids. For the working productive female, current feed analysis methods or estimates of "requirements" as energy and protein, bear no relationship to the balance of nutrients (amino acids, glucogenic compounds and long chain fatty acids) required to meet pregnancy or lactation in female draught animals.

The use of feeding standards or even presently recommended feed analysis systems appear to have little relevance to draught animals fed fibrous agricultural residues where the objective should be to "maximise draught power utilising available resources" rather than to meet the animal's requirements for a set amount of work. Using available feed resources to feed draught animals will rely heavily on maximising efficient rumen fermentation of a feed and balancing the nutrients for work with supplements. The simple provision of molasses/urea block to provide a range of microbial nutrients including urea for maximising rumen fermentative digestion appears to be an important strategy when animals commence to work (see Leng 1984).

Acknowledgements

I would like to thank Dr David Pethick for some of his unpublished data. In addition David alerted me to the fact that in his papers published on uptake of nutrients by skeletal muscle, the blood flow rates were in error by a factor of two. Whilst this affected the reported values for substrate uptake it did not affect the values for the contribution of different substrates to oxygen consumption in skeletal muscle. In this paper, where reported, the substrate uptake has been corrected.

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Some Considerations of Voluntary Feed Consumption and Digestion in Relation to Work

R. H. Weston*

THE performance of work involves energy expenditure which in turn necessitates additional dietary energy intake, nutrient digestion and energy release in tissues, as facilitated by a supply of essential nutrients. Accordingly, feed intake and digestion are critical to work function. Despite this relevance, the scientific literature of the past 50 years contains few specific references to voluntary feed consumption (VFC) and digestion in relation to work. Presumably this reflects the profound decline that took place during this period in the economic significance of draught animal power in the developed countries. Draught animals, however, continue to play important roles in many countries, and the objective of this paper is to examine VFC and digestion in relation to work. Accordingly, the main sections deal with VFC, digestion, and relevant research areas for future studies.

Voluntary Feed Consumption and Work

Historically, research into draught animal nutrition has been mainly centred around equines in developed countries. The absence of a useful body of data on VFC and the lack of significant research on the subject suggest that in these countries ad libitum feeding of draught animals indoors was not commonly practised. Presumably, restricted feeding was the general rule, possibly because reasonable quality roughages were available for maintenance feeding and concentrates were used to furnish work energy.

VFC regulation is complex in all animals, involving many factors that relate to the animal's metabolism, gastrointestinal function, feed palatability, and the environment. A wide range of factors act as determinants of VFC. Under optimal conditions of diet and environment, viz. palatable diet, absence of physical constraints to gastrointestinal tract function, and minimal environmental stress, feed intake is determined by the animal's energy demand. This demand in turn is a function of genotype, physiological state, diet nutrient status and work.

Level of Workload

As far as I am aware, no attempt has been made to determine the VFC response to a range of workloads in draught animals. Indeed, the only published study of this type appears to be that of Mayer et al. (1954) with the laboratory rat. In the absence of data specific to conventional draught animals the model derived from the laboratory rat data is used here to facilitate discussion. Figure 1 contains relative changes in VFC, body weight and an efficiency term with increasing workload in the rat as calculated from the data of Mayer et al. (1954). The work in these studies took the form of treadmill running at 1.61 km/hour by conditioned animals maintained under optimal dietary and environmental conditions; work of up to 8 hours duration each day was involved. The VFC response to increased workload had points of inflexion at about 1.4 km and 10.5 km, hence three ranges prevailed. VFC declined in the first range (0→1.4 km), increased in the second range (1.4→10.5 km) and decreased in the third (>10.5 km). The maximum VFC, equivalent to about 162% of the VFC with zero work, occurred at about 10.5 km. Between workloads of 1.5 km and 8.8 km, the proportional response zone, VFC increased linearly with work. Beyond about 9.5 km the animals became tired and required prodding to perform the work, a situation not without parallel in conventional draught animal usage. Accordingly this zone has been designated the exhaustion range. The body weights of the animals declined slightly with increased workload in the intial range, remained relatively constant in the proportional response range and declined again in the exhaustion range. It would seem reasonable to conclude that a state of energy equilibrium was approached in the proportional response range, whereas in the exhaustion range body tissue stores were metabolised to remedy a deficiency of dietary energy.

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Assuming energy equilibrium to prevail in the proportional response range, relative efficiency (work/feed) may be reasonably calculated and, as shown in Fig. 1, this increased with advancing

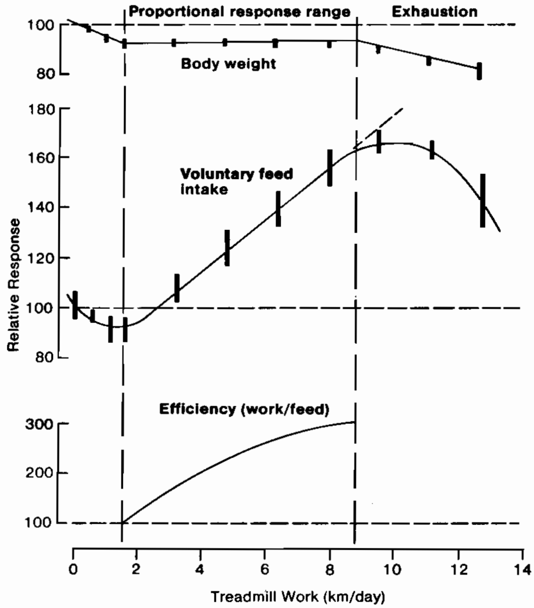

Fig. 1. The relative responses of body weight, voluntary feed intake and efficiency to increasing workload in the laboratory rat. The values are calculated from the data by Mayer et al. (1954) as obtained with rats exercised by treadmill running at 1.61 km/h.

workload, the value at 8.8 km workload being about three times that at 1.8 km. The recommended nutrient allowances for the equine (Morrison 1951) suggest increases in feeding level of 30, 60 and 100% above maintenance for light, medium and heavy work, respectively. Thus, the 8.8 km work with the laboratory rat, corresponding to a VFC increase above maintenance of 60%, could possibly be equated with medium work for the equine. Genotypes selected for draught purposes would be expected to do proportionately more work than the laboratory rat before fatigue initiates a decline in VFC; accordingly, in these genotypes the range of proportional VFC response could be relatively longer than that shown in Fig. 1.

The few published data on VFC in working bovines and equines are not inconsistent with the laboratory rat model. Thus VFC failed to increase in bulls subjected to comparatively light work (about 2 km walking/day) for prolonged periods (Pindak and Pilat 1976), whereas at the other end of the work range appetite was reported to decline in army horses subjected to prolonged strenuous work under field exercise conditions (Bengtsson 1975). In the range subjectively assessed as light-moderate work, VFC by adult horses increased by 13% in the studies by Sasimowski et al. (1979) and by amounts corresponding to increases in digestible energy intake of 27–30% in growing horses given nutritionally adequate diets (Orton et al. 1985a).

Physiological State

The animal's physiological state affects VFC, relevant data in this area for ruminants having been reviewed recently (Weston 1982). Although the potential economic value of female draught animals is widely recognised, there appear to be no data on the effect of work on the VFC of these animals when pregnant or lactating.

The situation with the pregnant ruminant is of particular interest. In general, the VFC of these animals does not increase to match the enhanced energy demand prevailing in late pregnancy. This compensation failure has been attributed to the physical effect of the gravid uterus on rumen capacity but this explanation is not completely satisfactory (Weston 1982). It is possible that the animal has a reduced capacity for energy disposal via pathways of maternal body tissue synthesis and that work could stimulate VFC because the resulting energy increment would be metabolised via oxidative pathways.

Non-working lactating cows and females of other species maintained under optimal dietary conditions are able to increase their energy expenditure and VFC when exposed to the cold (Kennedy 1953; Ragsdale et al. 1950, 1951). Clearly, enhanced energy disposal via pathways other than those of product synthesis occurs in lactating animals. Accordingly there would be reason to expect additive effects of work and lactation on VFC.

Light to medium work has been shown to increase VFC or digestible energy intake in both growing horses and growing rats fed nutritionally adequate diets (Meyer and Hargus 1959; Orton et al. 1985a). However, it remains to be determined whether draught animals can increase VFC sufficiently to sustain maximum growth combined with work.

Physical Preparation, Essential Nutrients, Heat Load

Poor physical preparation of animals, deficiencies of essential nutrients in otherwise optimal diets, and heat dissipation limitations represent conditions in which the animal's capacity to perform work may be restricted. The resulting reduction in work performance would limit the range of proportional VFC response (Fig. 1) and thus could be associated with less efficient feed use. However, no definitive data are available in this area.

Essential amino acids, glucogenic substrate, vitamins and minerals are included in the essential nutrients required for energy expenditure in work. To date there are no data on the requirements of these nutrients for the maximum expression of VFC in working draught animals. However, in the studies of Orton et al. (1985a) with horses, VFC responded to work although the diet provided only about 4 g digestible crude protein per MJ digestible energy. An equivalent level of digestible crude protein could be obtained by ruminants with diets of lower crude protein content. For example, roughages containing only 4–5% crude protein can provide, in ruminants, about 100 g or more crude protein digested in the intestines (DCP_i) per kg digested organic matter, the equivalent of about 5–6 g DCP_i per MJ digestible energy (Hogan and Weston 1967; Stephenson et al. 1983). Accordingly, the essential amino acid requirements of the working adult ruminant for the expression of maximum VFC may possibly be met by roughages of comparatively low protein content.

In considering protein allowances for ruminants, however, cognisance has to be given to the greater reliance of these animals, relative to monogastric animals, on amino acids as sources of glucogenic substrate (e.g. Leng 1970) inadequacy of which can affect feed intake (Ulyatt 1965). Whether or not the diet together with microbial synthesis provides adequate quantities of the vitamins B for the maximum expression of VFC in working draught animals remains to be assessed. Such vitamin requirements for the expenditure of energy during work have long been recognised. Thus, Cowgill et al. (1931) found that anorexia due to vitamin B complex deficiency developed much more quickly in dogs forced to exercise than in corresponding non-exercised subjects. Additional requirements for minerals must also prevail in working animals but, again, the appropriate requirements are not known. Minerals such as magnesium that are involved in muscle energy metabolism would be needed in increased amounts during work. A parallel situation prevails with increased energy output in the cold, increased magnesium intake being required for maximum feed intake (McAleese and Forbes 1961).

Thermal stress in hot environments reduces VFC in growing and lactating ruminants as reviewed by Weston (1982). However, no data are available on the effect of heat due to work on VFC under these conditions. In this context it is to be appreciated that heat production with work is high, 2–3 times more heat being generated when unit metabolisable energy is used for work than when used for milk production.

Gastrointestinal Tract Limitation

The physical regulation of VFC in relation to the capacity of the gastrointestinal tract to handle digesta is well recognised in herbage-fed bovines (e.g. Campling 1970) and probably prevails in herbage-fed equines. Such regulation may preclude the working animal consuming sufficient diet to satisfy its energy demand and accordingly may limit the range of proportional VFC response to workload (Fig. 1). Increases in VFC with herbage diets occur when the energy demand of the ruminant is increased by lactation, cold exposure, etc., and corresponding changes might be anticipated when energy demand is increased by workload. The magnitude of the herbage VFC response to enhanced energy demand appears to increase with increase in herbage quality. For example, the voluntary consumption of a low quality herbage that would provide a maintenance ration under standard conditions increased by only 1.5–2.3 g OM/day/kg body weight in sheep during cold exposure, the energy from this feed increment being calculated to provide only about 25% of the additional energy cost imposed (Weston 1970). By contrast, larger feed increments, 4.5–5.6 g organic matter/day/kg body weight, and greater compensation to cold stress, were obtained with higher quality herbage diets (Wheeler et al. 1963; Wodzicka-Tomaszewska 1963, 1964). Thus it is possible that the maximum VFC response to work with low-quality herbage diets may only furnish sufficient energy for low workloads. At the other end of the quality range, high-quality roughages as offered ad libitum would provide energy at twice the maintenance energy level in non-working ruminants (e.g. Weston and Hogan 1973) and accordingly would sustain heavy workloads without any VFC stimulation.

In herbage-fed bovines the clearance of digesta from the rumen is an important factor in VFC regulation and particle breakdown by chewing and ruminating is a rate-limiting process as reviewed by Weston and Kennedy (1984). However, no data appear to be available on the patterns of eating and ruminating during the day in working bovines fed ad libitum. Thus it would be interesting to know whether working for prolonged periods during the day is consistent with the maximum expression of rumination in bovines with enhanced VFC. This information could be of significance for low-quality herbages with which the time spent in chewing activities in non-working bovines can approach 14 h/day (Balch 1971).

Other Factors

The preceding discussion relates to a few of the generally more important determinants of VFC. Many other factors would interact with work to determine VFC in appropriate circumstances. Additional considerations include (i) VFC in pre-work periods when buildup in body condition could be required; (ii) possible compensatory increases in VFC in animals with depleted body stores following prolonged work coupled with inadequate nutrition; (iii) effects of supplements on VFC; and (iv) possible delays in the onset of the VFC response to work energy expenditure.

Digestion and Work

Few data are available on the effect of work on digestion. In pregnant cows, Ganovski (1984) found increases of 11–12% in organic matter and crude protein digestibilities and 19% in fibre digestibility with walking for 3 km daily. These changes contrast with small average decreases (<3%) obtained with lactating cows (Ellenberger and Schneider 1927). With working horses no clear picture has emerged. Olsson and Ruudvere (1955) summarised data available to them from three early studies. In two of these studies, digestibility was found to decline (up to 4%) at higher levels of work and in one study it increased (6%) with light work. However, no difference between light and heavy work was reported in a third study. Very recent studies with both low and medium protein diets containing 60% hay (Orton et al. 1985b) showed marked effects of work (trotting for 1 h at 12 km/h) on both dry matter digestibility (+20%) and crude protein digestibility (+17%). In these studies work was accompanied by an increase (9%) in the mean residence time of a water-soluble marker in the gastrointestinal tract and a decrease (11%) in the mean residence time of a solids phase marker; faeces dry matter content was also increased by work.

Although no consistent picture is shown with overall digestibility, consistent short-term effects of work in decreasing the rate of passage of digesta through the stomach and intestines are shown in man, dogs, rats and mice (e.g. Adams and Pembrey 1931; Biester 1931; Adams et al. 1932; Mangold 1932); the practice of providing animals with only a small morning meal prior to work is logical on this basis.

The effect of workload on digestibility clearly requires elucidation. Direct or indirect effects on digestibility could arise from changes in a range of factors including blood flow to the gastrointestinal tract, increases in body temperature, feed particle residence time in the gastrointestinal tract, and effectiveness of mastication on particle breakdown. In the ruminant, physiological state may influence various physiological processes resulting in alterations in nutrient yields. Thus cold exposure, late pregnancy and lactation have all been shown to increase rumen digesta clearance rate, and to be accompanied by a greater yield of digestible protein and a lower yield of digestible energy (e.g. Kennedy and Milligan 1978; Weston 1979). Understanding the nutrition of the working ruminant necessitates information on these various ruminal transactions. The key role played by nitrogen recycled to the rumen in the protein economy of the herbage-fed ruminant is now well recognised (e.g. Hogan 1982; Kennedy and Milligan 1980), and it is possible that work may influence this process. Blood urea concentration acts as one of the determinants of the extent of nitrogen recycling as reviewed by Kennedy and Milligan (1980) and could well be affected by work. Thus, in the adult working animal, amino acid metabolism may be enhanced without an increase in body protein storage. As a result urea concentration in blood could increase and permit additional nitrogen transfer to the rumen. Changes in the recycling of minerals to the rumen could, likewise, be affected by work.

The nature of rumen clearance transactions in animals fed ad libitum with herbage diets could also be relevant to work performance. Thus, rumen digesta load may vary with roughage type. For example, Leibholz (1984) found rumen digesta load with low-quality hay to be about 20% of body weight compared with about 12% of body weight with lucerne hay. The higher load with the lower quality feed must reduce the energetic efficiency of work.

Future Research

The preceding discussion highlights the absence of any significant body of published data on VFC and digestion in relation to work. The allocation of priorities for future reseach in these areas is difficult. Draught animals are used in different types of work at varying workloads under a wide range of economic, climatic and social conditions. Within these systems work output per unit feed has to be maximised as has the use of cheapest feeds, the use of feed types not required by humans, the exploitation of the most efficient genotypes, and the exploitation where possible of the nutritional advantages of ruminants. Within this framework, regional problems of high priority in the areas of VFC and digestion presumably exist but are as yet undocumented. In addition, more general problems may well prevail, the significance of which could emerge with the development of an understanding of the nutritional physiology of the working animal. In this context clear need exists for controlled studies on the effects of a range of workloads on various aspects of VFC and digestion including related measurements on rumen transactions. Nutrient requirements are of particular significance and need formulation in relation to regimes of ad libitum feeding. In such studies, adequate definition of conditions and the use of appropriately trained, conditioned, and acclimatised animals must be considered as essential.

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Nutritional Status of Draught Animals in Sri Lanka

M. N. M. Ibrahim*

CATTLE and buffaloes are employed extensively for draught in South and Southeast Asia for transport and rice cultivation. In Sri Lanka, cattle are mainly used for transport while buffaloes are used for field work. In recent years, new settlers in the Mahaweli areas increasingly use cattle for ploughing. Animal power, however, continues to be underutilised, partly because of the introduction of tractors and also the poor working condition of the animals.

Although farmers are aware of the extra needs of nutrients for growth, lactation and pregnancy, they usually ignore nutrition for draught animals because of limited benefits the farmer obtains in maintaining animals purely for draught (1-2 months of work/year). Unless the purpose of rearing is for milk and draught the animals would be idle for 9-10 months of the year.

In this paper an attempt is made to highlight the specific nutrient requirements for draught and the need for better feeding management during working periods. Also discussed are the different management practices adopted in Sri Lanka, the nutritional value of common feeds consumed by draught animals, and the ways to improve the traditional type of feeding management.

Distribution of Animals

The total cattle and buffalo population in Sri Lanka is 1.6 and 0.88 million, respectively, distributed countrywide over 25 agricultural districts (Livestock Census and Statistics 1982). Of the total population, 80% of the cattle and 65% of the buffaloes are owned by smallholders. National surveys on the number of animals available for draught purposes are lacking, so one has to depend on estimates. Illanganthilak and Ramanan (unpublished data) estimated that 40% of the total buffalo population is available for draught. This estimate was arrived at by assuming that only the trained and healthy adult males and cows not in milk are available for draught.

Based on the rainfall pattern the agricultural districts are categorised into wet, intermediate and dry zones. The zonal distribution of buffalo, those available for draught and used in paddy cultivation, and the extent of land cultivated using buffaloes are shown in Table 1.

Although the dry zone has about 51% of the buffalo work force and 57% of the total cultivated land during 82/83 Maha season (October/January), only 28% of the ploughing was done using animal power. But, in the intermediate and wet zones, 62% and 48% respectively, of the land preparations were done using buffaloes. These figures are in close agreement with the study reported by Ryan et al. (1982), where the acreage ploughed using animal power in the wet, intermediate and dry zones was 42, 63 and 26%, respectively.

Some of the reasons for the underutilised animal power in the dry zone are: low power output as a result of poor condition; lack of facilities for wallowing, etc., during working periods; and uncertain weather conditions (low and high rainfall) necessitating field operations to be completed within very short periods.

With greater pressure on dry zone land especially in the Mahaweli project areas, both the landholding size and herd size would decline and hence farmers would have to depend on more intensive integrated crop/livestock systems. Such changes are already seen among settlers in the Mahaweli area.

Nutrient Requirements

As in the case of other productive functions, draught also requires nutrients such as energy, protein, minerals and water. The requirements for these nutrients is determined by factors such as age, weight, type of work, amount of power generated, duration of work, and the speed of travel. There are different guidelines on the classification of work into light, medium and heavy. Munzinger (1982) categorises on the basis of type of work performed:

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Table 1. Availability of draught animals and cultivated area using animal power in Sri Lanka (1982/83—October to January).

Agroclimatic zone	Buffalo population ('000)	No. of buffaloes available for ploughing ('000)	Extent cultivated ('000 ha)	No. of buffaloes utilised for ploughing ('000)	Extent ploughed by buffaloes ('000 ha)	% ploughed by buffaloes
Wet	181.30	77.32	144.89	27.32	55.57	48.4
Intermediate	240.30	96.12	120.90	31.42	75.40	62.4
Dry	445.60	178.24	353.30	40.69	97.67	27.6

Source: Agricultural Implementation Programme 82/83, a Working Document. Ministry of Agricultural Development and Research.

light (sowing, transport), medium (harrowing, cultivating), and heavy (training, ploughing). FAO (1972) classifies light medium and heavy work on the basis of the number of hours worked, namely 4, 6 and 8 hours respectively. More recently, Goe and McDowell (1980) have based the energy requirements on intensity (% of body weight developed as draught) and the number of hours of work performed. A suitable guideline needs to be recommended for future use. Another vital question to be debated is whether the requirements for buffalo are the same as those for cattle.

The energy and protein requirements for maintenance, growth and for performing work as recommended by Munzinger (1982) are given in Table 2. Energy requirements based on metabolisable energy system (calculated from TDN and using equation) are also included for comparison. It seems evident that the ME values calculated from TDN values and those estimated directly are similar.

It is noteworthy that the energy requirements for draught could be as high as 2.5 times its maintenance in times of heavy work. Such amounts of energy output are equal to 6–8 kg of milk.

Goe and McDowell (1980) reviewed the research undertaken on the protein needs for draught and concluded that, if the maintenance ration is adequately balanced, extra protein supply for work is not necessary. But one should be cautious in widening the protein to energy ratio in draught animal rations as it could depress palatability, digestibility and also increase metabolic heat loss (Maynard and Loosli 1969).

As indicated earlier the energy requirement of working animals could be several times the daily maintenance requirement. Under good quality feeding situations the extra food required to meet energy requirements will inevitably supply the animal with additional minerals. Under tropical feed situations, based on natural grasses and crop residues, this may not be the case.

Usually sodium and chlorine are efficiently conserved and in adult animals its maintenance needs are extremely small. But, in conditions of excessive sweating the losses of these elements could be considerable. Thus the dietary requirement of the working animal for salt is raised above that of a non-working animal. Under Sri Lankan conditions, the sodium content of pastures and residues is extremely low (Table 3) and hence supplementation with salt is vital for both non-working and working animals. Furthermore, with working animals the requirement would depend on the climatic conditions prevailing during the working periods.

Sri Lankan pastures are also deficient in phosphorus and reports of animals responding to vitamin B12 indicates that cobalt content could be also marginal (Ranawana et al. 1982). When feeding animals with crop residues such as rice straw it is essential to feed complete mineral mixtures.

According to Munzinger (1982), the average daily water requirement for Zebu cattle (Africa) during the rainy season and dry season is 16 and 21 litres, respectively. He also recommends the provision of 10 litres more for animals performing medium to heavy work. Under Sri Lankan conditions, there is a need to estimate water requirements for the different climatic zones.

As most of the draught animals are invariably fed on crop residues, it is important to stress that the intake of water via feed is negligible (1 kg/10 kg feed intake). Adequate water should therefore be made available at all times.

Management

Considerable variation in the management of draught animals exists and this in turn influences the feeding practices. These variations in management are due to: agroclimatic zone, type of farm holding, size of farm holding, availability of grazing land (scrub jungles, reservations, etc.), and purpose of rearing animals (draught only or draught and milk).

The general situation as regards the different feeding/management practices involved in Sri Lanka could be summarised as follows:

Table 2. Energy and protein requirements for draught cattle.

	TD (kg)	ME[a] (MJ/day)	Digestible protein (g)
Maintenance requirement (Mm)			
(LW in kg)			
200	1.7 (25.6)	26.5	120
300	2.3 (34.6)	35.5	180
400	2.8 (42.2)	44.6	240
600	3.8 (57.2)	62.9	360
Growth			
Additional allowance for 300 kg animal gaining			
100 g/day	0.26 (3.92)	4.71	17
300 g/day	0.87 (13.10)	11.26	52
Work (Total requirement)			
Light work (sowing/transport)	1.5 × Mm requirement		60/100 kg LW
Medium-heavy (cultivation/harrowing)	2.0 × Mm requirement		80/100 kg LW
Heavy (ploughing/training)	2.5 × Mm requirement		80/100 kg LW

Source: adapted from Goe & McDowell (1980).
Figures in parentheses are ME requirements (MJ/day) calculated from TDN values.
(TDN × 15.06)
[a] Estimated according to Technical Bulletin 33, Ministry of Agriculture, Fisheries and Food, U.K.

(a) Based on the rainfall pattern, the major cropping seasons in Sri Lanka are the Maha Season (October–January) and Yala Season (May–July). Hence, the management practices vary accordingly.

(b) During the working period (rainy season) and non-working period (part of the rainy and dry season), natural grasses growing in scrub jungles, reservation lands, roadside, along irrigation ways, and paddy field bunds form the major source of green feed. Most farmers normally feed rice straw.

(c) After harvesting the paddy crops the animals are generally allowed to graze in the paddy field. During this period the animals are also used for threshing paddy.

(d) In most cases during the working period the animals are frequently kept in the farmers' homestead or in the immediate vicinity. Such a situation is advantageous in advising farmers about better feeding practices.

(e) After land preparation and establishment of paddy, the animals are moved to jungle lands, waste lands, or let free to graze on roadsides.

(f) In some dry zone districts the animals are handed over to professional herdsmen where they manage in large herds.

(g) In the wet zone and some parts of the intermediate zone the animals usually graze along roadsides during the day and are tethered or paddocked during the night. This is another instance where the farmer could be influenced to feed better (at least ad libitum feeding of rice straw in the night).

(h) The animals grazing in jungles during non-working seasons are usually in better condition than those kept in farmers' living areas.

(i) During periods of continuous drought, some farmers feed tree leaves, banana trunks, legume tree leaves, and rice straw.

(j) the scrub jungle grazing lands are rapidly decreasing after the onset of the new settlement schemes. In the near future farmers will be looking for alternate feeding management practices.

(k) The cart bulls (oxen) are generally better fed (i.e. fed to appetite) with available roughages than working buffaloes. These cart bulls are generally worked thoughout the year.

(l) As cart owners make their living by transporting goods, they are compelled to feed and manage the animals better. Some farmers transport their goods as far as 40–50 km. The animals are usually worked during the late afternoons and at night. During daytime (after 10.00 am) the animals are tethered and allowed to graze along the roadside, and are also fed rice straw. Some farmers also feed rice bran and salt. Straw in rope nets is hung between the animals

Table 3. Nutritive value of some Sri Lankan feeds.

Species		Ash (% DM)	Macro elements (mg/g DM) Na	Ca	Mg	P	Crude protein (% DM)	IVOMD (%)	ME (MJ/kg DM)
1	2	3	4	5	6	7	8	9	10
Grasses									
Panicum maximum Jacq.	Guinea A	10.8	0.6	3.6	2.1	1.1	16.7	52.6	6.5
Brachiaria brizantha Stapf.	Palicade grass	10.2	0.4	2.2	2.5	1.2	13.6	50.0	6.2
Brachiaria ruzisiensis	Ruzi grass	10.1	0.3	2.7	2.9	1.9	12.5	63.2	8.0
Setaria sphacolata	Seteria	5.4	0.1	3.8	2.2	0.9	13.1	64.3	6.6
Echinocloa colonum (L) Link.	Maruk	9.8	0.6	1.5	3.2	1.4	14.5	64.5	7.9
Eleusine indica (L)	Goose grass	9.7	0.1	4.5	4.4	0.9	—	68.2	7.4
Pennisetum polystachyon (L) Schutt.	Fox tail	8.3	1.5	2.2	3.2	1.4	11.3	60.8	7.8
Fimbristylis littolaris	Kudamatto	9.8	0.3	6.8	2.5	1.4	15.2	67.4	8.1
Paspalum spp. 80% *Axonopus* spp. 20%	Carpet grass	3.4	—	—	—	—	10.7	62.3	7.8
Axonopus affinis Chase.	Carpet grass	6.5	—	2.1	1.6	—	13.4	47.8	6.5
Axonopus affinis 80% *Cyperous* spp. 20%		3.4	—	3.9	2.7	—	11.1	48.9	6.5
Ischaemum aristatum Hook.		5.6	—	4.1	2.4	—	11.9	54.2	7.1
Panicum ripens (L)	Couch grass	7.4	—	4.0	2.6	—	10.9	49.5	6.6
Cyanodon dactylon 60% *Digitaria* spp. 40%	Doub grass	9.5	—	6.1	2.2	—	13.9	48.2	6.3
Legumes									
Stylosanthus goyanensis	Stylo	6.1	0.5	10.9	2.1	0.6	19.1	63.5	8.5
	Siratro	7.6	0.6	6.9	2.3	1.5	20.5	64.3	8.5
Tree Legumes									
Gliricidia maculata	Gliricidia	9.3	0.5	7.1	3.3	1.5	23.8	67.2	8.8
Leucaena leucocephala	Ipil-ipil	7.7	1.1	15.9	3.6	2.6	29.3	59.7	7.6
Erythrina variegata	Dadap	7.3	0.8	3.4	1.9	0.7	24.9	54.3	7.1
Tree leaves									
Artocarpus heterophyllus	Jak	9.4	0.3	15.1	1.9	1.2	17.5	39.7	4.8
Michelia nilagirica Zenk.	Wal-sapu	6.2	0.2	5.3	2.0	0.7	16.2	42.1	5.3
Crop residues									
Oryza sativa	Rice straw	13.3	—	5.9	1.8	—	4.8	47.9	6.0
	Rice straw (Urea treated)	13.1	—	6.2	1.8	—	10.2	54.6	7.0
	Rice bran (average)	—	—	1.8	6.9	1.0	—	—	—

and this enables them to eat even while they are moving.

Nutrient Content of Feeds

The chemical composition and nutritive value of some of the grasses obtained from the roadside, paddy field bunds, and other grazing areas, and other feeds which are used in animal feeding such as tree legumes, tree leaves, and rice straw, are presented in Table 3.

The crude protein content of the natural grasses ranges between 10 and 15%. These samples were collected from areas where animals are usually continuously grazed and most of the species were before pre-bloom stage. The legumes, tree legumes, and the tree leaves had more than 15% crude protein. Provided that the digestibility of the protein from the above sources is greater than 60% and also sufficient quantities are available, adult working

Table 4. Composition of rice/straw-based ration and their costs for draught animal sustaining medium work and heavy work (350 kg liveweight).

Ration 1		Ration 2		Ration 3	
Ration (kg)	Price (Rs/day)	Ration (kg)	Price (Rs/day)	Ration (kg)	Price (Rs/day)
Maintenance					
7.0 US[a] 0.8 RB[d]	0.83	7.3 SS[b] No supplement	1.46	6.3 TS[c] No supplement	2.63
Draught					
Medium work					
7.4 SS 1.2 RB	2.25	7.0 US 3.6 RB	2.51	7.8 TS —	4.15
Heavy work					
7.4 SS 2.8 RB	3.14	9.8 TS —	3.91	7.0 US 4.0 RB 0.4 CPO[e]	4.15

[a] Untreated rice straw
[b] 2% urea-sprayed (supplemented) rice straw
[c] Urea-ammonia treated rice straw
[d] Rice bran
[e] Coconut poonac
Source: Straw Utilisation Project—Miscellaneous Report No. 9, 1984. Department of Animal Science, University of Peradeniya.

animals having access to such feed could satisfy their daily protein requirements. But in practice, due to the heavy grazing pressure and low productivity, the animals are unable to obtain sufficient quantities. The grazing time is not a limitation but the amount of feed harvested per bite is very small.

The in vitro organic matter digestibility (IVOMD) of these samples ranged from 40 to 69%. The higher values obtained could be partly due to the stage of maturity. At mature stages of growth (after flowering) the IVOMD of natural pastures could be as low as 30% (Peiris and Ibrahim—unpublished data). The energy values of these feeds, estimated using 'D' values (in vitro DOMD), are also given in Table 3. The values range from 6 to 8 MJ/kg dry matter.

Rice straw which is abundantly available virtually at the farmers' homestead is not fully utilised. Although the ME content of straw is around 6 MJ, it is low in protein and useful minerals. With better quality straw, when offered ad libitum, the animals could consume up to 2.5% of body weight.

Adequate levels (mg/g DM) of calcium, magnesium, phosphorus and sodium that should be present in green forage to satisfy animals needs are 3.5, 1.0, 1.5 and 1.4, respectively (Ranawana 1984). On this basis, the feed materials presented in Table 3 are adequate in Mg, but often marginal in Ca. The P and Na contents are on the low side.

Nutrient Requirements

An adult animal weighing 300 kg would require 35 MJ energy and 180 g of digestible protein per day for maintenance. Even the natural pastures discussed above could satisfy this requirement provided sufficient quantities are available. For example, an intake of 5 kg dry matter of a feed with an energy value of 7 could supply this requirement. This would mean that the animal will have to consume about 25 kg of fresh material/day. Just after the working period when animals are allowed to graze freely in the scrub jungles they could harvest sufficient quantities. The herbage situation after 3–4 weeks in these areas has not been assessed and hence is difficult to comment on at this stage. Furthermore, the animals might have to expend energy in walking long distances in search of food. These problems become more acute with growing and pregnant animals.

During the working periods the animals are kept close to the farmer's homestead and the green feed availability is low. However, the farmers have their own freshly threshed straw. If the energy value of straw is 6 MJ/kg DM, by consuming 6 kg DM an adult animal weighing 300 kg could easily meet its maintenance energy needs. The ration, however, is deficient in protein and minerals. Such a situation could easily be corrected by feeding legume tree leaves (*Gliricidia*, Ipil-ipil, *Erythrina*) or a cheap concentrate such as rice bran, and also salt (Table 4).

In performing heavy work the energy requirement is increased by 2.5 times its maintenance level, i.e. a 300-kg animal requires about 88 MJ/day (Table 3). The additional energy expended in performing heavy work is equivalent to that required to produce 6–7 kg of milk. In Sri Lanka, as a common practice, the farmers usually rest the animals for one day for every 3–4 days of continuous work. This indicates that the farmers are aware of the heavy energy expenditure in performing work. Under heavy working conditions it is not possible for the animal to obtain the energy from untreated straw alone even when fed ad libitum. Feeding practices based on untreated straw/grass and/or concentrates or treated straw with or without concentrates should be worked out. An example of such a calculation is shown in Table 4. The use of untreated straw-based rations for productive purposes demands the use of concentrates.

Although rice bran is comparatively cheap and also generally available, its quality as assessed by in vitro digestibility could range from 40–60%. Moreover, the choice between feeding untreated, urea-sprayed or urea-ammonia-treated rice straw is an economic issue and to a large extent depends on the price of rice bran at the time of need.

Conclusions and Future Research Priorities

Sri Lankan draught animals are underfed, and farmers should be made aware of the value of straw and encouraged to use it as feed by having a few stacks or heaps of straw in the night paddocks, or hung in rope nets. The feeding of common salt should be encouraged at all times.

Other areas needing verification or further study include:

1. The use of cattle nutrient requirement data on buffaloes needs to be verified;
2. Continuous assessment on the nutritional status of adult, growing and lactating animals should be made;
3. More information is needed on the feeds usually consumed by animals during both working and non-working periods;
4. A uniform set of figures on the nutrient requirements for draught animals performing different types of work should be made available;
5. Simple pretreatments, such as chopping or spraying of a salt solution, to encourage intake of straw need to be further investigated.
6. Continuous assessments of the draught capabilities throughout the working period should be made. In Sri Lanka, this type of measurement should be done on: (a) animals which are grazed in jungles and brought to the farmer's homestead only during the working period, and (b) animals which are permanently kept on the homestead.

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Nutritional Status of Draught Buffaloes and Cattle in Northeast Thailand

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BUFFALOES have been playing an important role in the Thai farming system for generations, serving as draught power, and providing meat and other useful by-products. They also represent wealth to the farmer and can be passed on to relatives as an inheritance. Cattle are also raised as draught power in certain areas, but are mostly sold for slaughter.

Most water buffaloes and cattle are raised by small village farmers at the subsistence level where feeds are dependent on subsequent cropping systems. Seasonal patterns greatly influence the availability of feeds which in turn affects the performance of the draught animals (Wanapat 1981).

Herds of buffaloes are usually small, averaging 2–3, and are closely influenced by size of cropping land and available family labour. For cattle, the herds are far larger, particularly those raised for meat. The population of buffaloes and cattle in Thailand is shown in Table 1. Classification by age, sex and purpose of raising is provided by the National Statistical Office (1978), giving the total population of buffaloes and cattle for the entire kingdom as 5.6 and 4.1 million head, respectively. However, the figures reported by the Office of Agricultural Economics (1982) were 6.1 and 4.5 million, for the year 1981. Most buffaloes and cattle over age 3 were raised purposely for draught power. This is also true of the northeast region, which contains 65 and 41% of the buffalo and cattle population. Working duration of water buffaloes was compiled by Konanta et al. (1984), and showed the average working period to be 122 days/year and 5 hours/day.

Traditional Management Practices

The responsibility of raising water buffaloes and cattle rests with young school children or the older people. The pattern of herding these animals is considerably affected by seasons.

Wet Season

Normally, in the mornings the animals are tethered to self-feed on straw prior to being herded out into the paddy fields. The farmers allow the animals to graze grasses in the open paddies and along the rice bunds until all areas are fully cultivated. Cut-and-carry of native grasses from nearby fields is also practised. During the transplanting period, where all areas are cultivated, rice straw that has been saved is fed to the animals to ensure full feeding, especially to the working ones. Ploughing and harrowing using working animals are usually done early in the morning and in late afternoon when temperatures are not too extreme. Between working hours buffaloes will be fed and allowed to wallow in muddy ponds.

In areas where field crops are adjacent to rice fields, animals are often tethered to graze on available grasses. Some predominant species are: Ya Prak (*Cyanodon dactylon*), Ya Chun Argart (*Panicum repens*), Ya Park Kwauy (*Dactyloctenium aegyptium*), Ya Kao Nok (*Echinochloa crus-galli*), and Ya Sai (*Leersia hexandra*).

De Boer (1972) reported that rice fields and upland fields available for animal grazing declined remarkably from June to November (Fig. 1), thus time spent grass cutting by the farmers was significantly increased during this period especially July and August.

Buffaloes and cattle showed specific preferences when grazing. Buffaloes could efficiently graze at lower levels of grasses and could also graze in flooded areas, whereas cattle preferred to graze in the dry areas.

Dry Season

During the early dry season, all animals are herded out early in the morning into open fields, public communal grazing areas, upland fields, or roadsides to graze on native grass and rice stubble.

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Table 1. Population of buffaloes ana cattle in Thailand.

	Thailand		Northeast	
	Cattle	Buffaloes	Cattle	Buffaloes
Age, year				
< 1	508 500	555 700	208 000	361 400
> 1-2 for cattle and > 1-3 for buffaloes	860 600	1 159 200	338 100	734 800
Male	430 100	584 600	162 400	370 700
Female	430 500	574 600	175 800	364 100
> 2 for cattle and > 3 for buffaloes	2 771 200	3 896 700	1 150 600	2 543 100
Male	1 213 100	1 747 600	466 400	1 155 800
Draught	1 052 400	1 696 200	395 100	1 131 300
Other	160 700	51 400	71 100	24 500
Female	1 558 800	2 149 100	684 200	1 387 200
Milking	137 600	—	78 000	—
Draught	479 300	1 917 600	126 700	1 258 500
Other	941 900	231 500	479 500	128 700
Total	4 141 000	5 611 600	1 696 700	3 639 200

Modified from the National Statistical Office (1978).

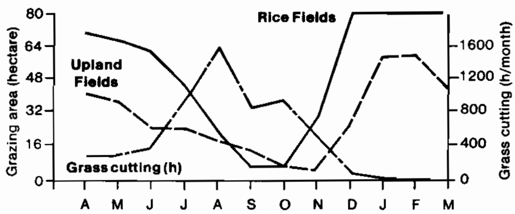

Fig. 1. Grazing pattern and grass cutting throughout a year (De Boer, 1972).

As the dry season progresses, the amount of these feeds declines gradually, particularly the grasses. By March and April, the areas appear to be almost barren. Rice straw then becomes an essential feed resource during this critical period. Thummasang (1985), based on a survey in three villages in the rainfed area and two villages in the irrigated area, reported that 71 and 95% respectively of the farmers save rice straw to be fed to animals. Corresponding figures for the rainy and dry seasons were 79 and 72% respectively. A comparison of rice straw and stubble quality of rice plants grown in the irrigated and rainfed areas was done by Tangtong and Wanapat (1985). They found that duration of straw storage and stubble remaining had little effect on its quality. Nevertheless, differences between the crude protein (CP) content of rice straw were higher than for stubble in both areas. In the irrigated area, rice stubble had a value of *in vitro* organic matter and digestibility higher than for rice straw (Table 2, 3). Similar findings were also reported by Hart and Wanapat (1985) in relation to the quality of rice straw and stubble. Sources of feedstuffs, season of feeding, location of availability, feeding practices and nutritive values, as practiced by small village farmers, are summarised in Table 4.

Effects of Seasonal Feedstuffs

Several surveys conducted in villages in northeast Thailand including work by Rufener (1971, cited by Rufener 1975) (Fig. 2) revealed seasonal patterns of animal growth. Based on information from the two villages, significant depressions of growth of working, nursing and growing buffaloes and cattle were markedly dropped during December to April which coincided with availability of low-quality feedstuffs. It was also reported that buffalo parturition was seasonal, during October–March (Rufener 1975) and November–April (Thummasang 1985). Buffalo calf mortality rate varied from as low as 10% (Rufener 1975) and 12.5% (Yano 1985) to as high as 35% (Lohr and Bhannasiri, unpublished) especially below 6 months old. If calves survived, however, they showed retarded growth. Possible causes of high calf mortality rate included malnutrition, parasites (*Toxocara vitulorum* and *Strongyloides papillosus*) and contagious diseases. However, the incidence of malnutrition would worsen the impact of parasites and diseases. An anonymous Thai report states that apart from worm infection, another cause of calf mortality is insufficient milk supply by the dams. This is particularly the case with calves born during the dry season. The relationships among availability of feeds, milk production and work are illustrated in Fig. 3. Amount of feeds and their quality do not only affect growth rates but also affect amount of milk produced during this critical nursing period. Draught power was in full operation from May to October when feeds were critical for the first 120 days prior to the heavy work season for the animals.

Table 2. Nutritive value (%DM) of rice stubble and rice straw grown in the irrigated area.

Duration	DM%	Ash	CP	NDF	ADF	ADL	Ca	P	IVOMD
At harvest									
Stubble	49.3	13.4	2.8	70.6	48.2	5.3	.3088	.0282	52.8
Straw	88.7	13.1	3.6	75.2	53.6	5.5	.4614	.0431	44.4
After harvest, 1 month									
Stubble	60.6	16.1	2.8	76.0	52.5	5.2	.2841	.0346	48.2
Straw	91.0	12.8	3.0	74.2	51.9	5.3	.5418	.0472	46.8
After harvest, 2 months									
Stubble	84.6	16.2	2.9	77.6	56.8	7.8	.2958	.0342	50.8
Straw	91.6	13.5	3.4	73.9	50.8	4.6	.4518	.0445	46.5
After harvest, 3 months									
Stubble	90.7	19.7	2.9	76.9	64.3	5.3	.3829	.0352	51.2
Straw	91.7	13.1	3.4	74.4	54.6	4.9	.4995	.0476	46.2
After harvest, 4 months									
Stubble	92.1	19.1	2.8	77.8	64.3	6.4	.3560	.0315	52.9
Straw	90.9	14.5	3.3	74.4	56.2	4.9	.4077	.0385	44.2
Stubble ($\bar{X}$ ± S.D.)	75.4±19.4	16.9±2.5	2.8±.04	75.8±3.0	57.2±7.2	6.0±1.1	.3255±.04	.0327±.00	51.2±1.9
Straw ($\bar{X}$ ± S.D.)	90.8±1.2	13.4±.6	3.3±.2	74.8±1.0	53.4±2.1	5.1±.4	.4724±.05	.0444±.01	45.6±1.2

Source: Tangtong and Wanapat (1985).

Table 3. Nutritive values (%DM) of rice stubble and rice straw grown in the rainfed area.

Duration	DM%	Ash	CP	NDF	ADF	ADL	Ca	P	IVOMD
At harvest									
Stubble	38.5	8.8	2.4	69.6	44.4	5.6	.2608	.0391	49.2
Straw	89.6	13.3	2.4	73.8	51.3	4.7	.5039	.0413	47.3
After harvest, 1 month									
Stubble	49.8	12.0	2.2	74.2	50.0	5.3	.3499	.0356	48.9
Straw	90.1	13.0	2.4	74.2	52.6	5.1	.4466	.0413	47.4
After harvest, 2 months									
Stubble	85.6	13.9	2.3	76.6	54.2	6.3	.2964	.0374	48.8
Straw	92.5	12.8	2.7	73.4	52.0	5.4	.5101	.0438	46.8
After harvest, 3 months									
Stubble	92.5	16.3	2.2	78.8	65.3	5.4	.3161	.0394	46.4
Straw	92.0	12.7	2.8	73.0	54.1	5.4	.4636	.0408	47.1
After harvest, 4 months									
Stubble	91.8	19.0	2.2	78.0	62.2	6.0	.3496	.0359	48.3
Straw	91.8	14.1	2.2	76.0	56.6	4.7	.5524	.0350	47.2
Stubble ($\bar{X}$ ± S.D.)	71.6±25.6	14.0±3.9	2.3±.1	75.4±3.7	55.2±8.6	5.7±.4	.3146±.04	.0375±.00	48.3±1.1
Straw ($\bar{X}$ ± S.D.)	91.2±1.2	13.2±.6	2.6±.2	74.0±1.2	53.3±2.1	5.1±.3	.4953±.04	.0404±.00	47.1±.2

Source: Tangtong and Wanapat (1985).

Effect of Feed Supplementation

Information is very limited, especially for working water buffaloes and cattle. Very recently, a study was conducted by Konanta et al. (1984) on a comparison of draught performance of crossbred Murrah buffaloes (50%) and native water buffaloes. Sixteen crossbred Murrah and 16 native water buffalo bulls, 2.5–3 years of age, were randomly allotted into a 2 × 2 × 2 factorial arrangement in a completely randomised design. Factors employed were breed, supplementation and working. Feeding trials lasted for six months, free grazing was allowed during the day and a supplement given at 1.5 kg/hd/d at night (Table 5, 6). Average daily gains (ADG) of the buffaloes were significanly higher when supplementations were made in both groups. Buffaloes used as draught had lower ADG in both groups of feeding (suppl. and no suppl.) and in both groups of animals. However, average daily gains between the crossbred and the native buffaloes were similar regardless of forms of feeding and working. In terms of ploughing capacity, native water buffaloes when given a supplement, performed far better ($P < .05$) and supplementation also tended to yield a faster rate of ploughing in all cases.

Table 4. Sources of feedstuffs, feeding practices and location of availability.

Source of feedstuff	Seasonality	Location	Feeding practice	Nutritive value
Native grass	Dry	Paddy field Public area Roadside	Spot-tethering Grazing	Low
	Rainy	Paddy bund Allotted dry area Edges of field crop Public area Roadside	Grazing Spot-tethering Lead-grazing Cut-carry	Average-good
Rice straw	Dry, Rainy	Rice-threshing floor Paddy field storage Homestead storage	Self-feeding Hand-feeding	Low
Rice stubble	Dry	Paddy field	Free-grazing Spot-tethering Cut-carry	Low
Wastes and agricultural by-products e.g.				
Cassava chip waste	Dry	Field	Free-grazing Hand-feeding	Good
Cassava leaf	Dry	Field	Hand-feeding	Good
Rice seedling top	Rainy	Paddy field	Hand-feeding	Good
Peanut residue	Dry	Field	Hand-feeding	Average
Water hyacinth	Dry	Homestead	Hand-feeding	Average-good
	Rainy	Pond	Free-grazing	Good
Shrubs and browses	Dry, Rainy	Upland Public area Roadside	Free-grazing	Low-average

Wanapat (1985, unpublished data).

Table 5. Weight changes of buffaloes as affected by supplementation and/or working.

	Crossbred Murrah				Swamp			
	no suppl.		suppl.		no suppl.		suppl.	
	work	no work	work	no work	work	no work	work	no work
Avg. Int. wt. (kg)	243.8	320.8	289.0	276.8	289.3	266.8	293.0	284.5
Avg. final wt. (kg)	311.5	371.0	329.5	349.8	302.8	312.3	332.5	353.3
ADG (g)	99.2^{a}	280.7^{b}	226.2^{b}	407.8^{c}	75.4^{a}	254.2^{b}	220.7^{b}	384.[illegible]

Means with different superscripts significantly differ ($P < 0.05$) (Konanta et al. 1984).

Table 6. Working ability of buffalo as affected by supplementation and/or working.

	Crossbred Murrah		Swamp	
	no suppl.	suppl.	no suppl.	suppl.
Ploughing capacity, ha/head/h	.036^{a}	.036^{a}	.038^{a}	.048^{b}
Rate of ploughing, m/min	40.7^{a}	48.2^{a}	43.9^{a}	53.3^{a}

Means with different superscripts significantly differ ($P < 0.05$) (Konanta et al. 1984).

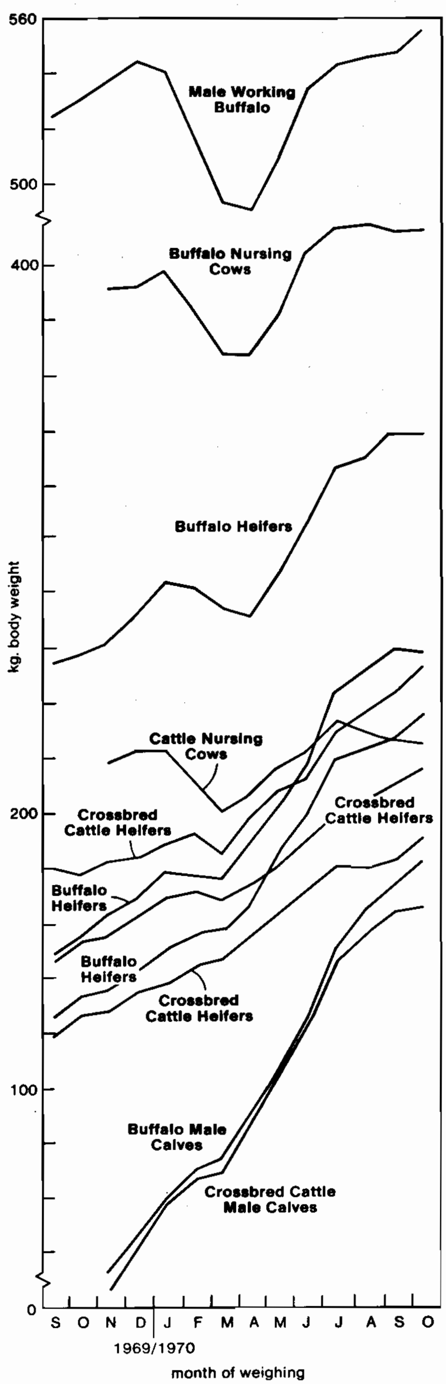

Fig. 2. Montnıy changes in body weight of selected animals in village 1 (Rufener 1975); the same pattern was shown for village 2.

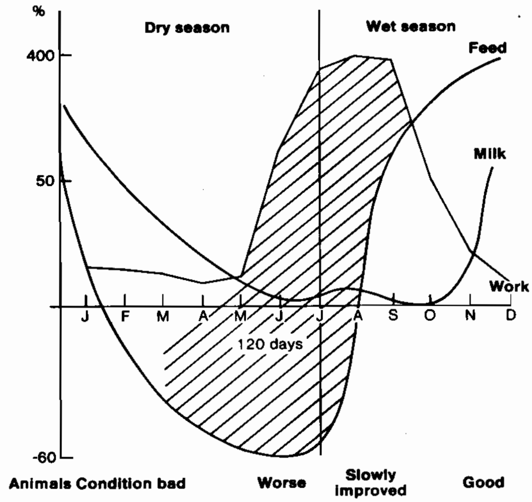

Fig. 3. Effects of feeds availability on animal conditions, milk production and working (Anonymous, unpublished data).

Conclusions and Suggested Research Priorities

Feeding practices commonly used by smallholder farmers are simple, and depend on naturally available feed resources, particularly crop by-products in various seasons. Therefore, performance of livestock in terms of liveweight, reproduction, and working ability is influenced by seasonal feeds and level of feeding. The following suggestions are made for further research on draught animal nutrition.

1. The availability and quality of seasonal feedstuffs, agricultural by-products, browses and shrubs should be investigated.
2. The feasibility of improving the utilisation of low-quality fibrous agricultural residues either by means of supplementation and/or treatment should be studied.
3. A table of feeding of available feedstuffs should be seasonally tailored according to working patterns.
4. Effects of feeds, level of feeding, treatment and/or supplementation should be conducted in regard to working ability.
5. Fattening of growing buffaloes and retired working ones for market should also be investigated.

Acknowledgement

The author would like to thank the Australian Centre for International Agricultural Research (ACIAR) for financially supporting his participation in the workshop.

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Relevance of the British Metabolisable Energy System to the Feeding of Draught Animals

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THE essence of the British system (ARC 1980) for calculating the feed needed to satisfy a ruminant's energy requirements may be expressed as:

$$ME = (B + W)/K_M + T + G/K_G + U/K_U + L/K_L)$$

and $I = ME/V_P$

where ME is metabolisable energy required;
I is feed required;
B, W and T are heat produced, or the energy content of body tissues completely oxidised, in, respectively, basal metabolism, work and thermal homeostasis;
G, U and L are energy in gain, foetus and milk;
K is efficiency of utililising ME for maintenance (M), gain (G), pregnancy (U) and lactation (L);
and V is ME per unit feed at maintenance, corrected for plane of nutrition (P) in lactation.

The terms on the right side of the equation can be measured or obtained from reference texts but ideally they should be predictable from readily observed attributes of the animal or its diet. The ARC has listed their 'preferred' values or methods of prediction.

Brody (1945) measured B in a wide variety of mature animals and found that it averaged 295 kJ/day/kg$^{0.73}$ of fasting weight with variation due to physiological state and species. The Agricultural Research Council (ARC) in Britain lists values of B for growing, pregnant and lactating sheep and cattle in MJ/day/kg$^{3/4}$ fed weight (the latter being 8% more than fasting weight).

For sheep and cattle, W is 0.26 kJ/kg for the double movement of lying down and standing up again and 10 kJ/kg.day for remaining standing. Expenditure in locomotion is horizontal component 0.002 kJ/kg.m and, vertical component 0.028 kJ/kg.m; grazing incurs an expenditure of 2.2 kJ/kg.hr.

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K_U is 0.13; K_M, K_G and K_L are calculated from ME/GE at maintenance (GE is gross energy) and are 0.62–0.75, 0.26–0.54 and 0.53–0.66, respectively, for feeds of digestibility 0.40–0.85. When body reserves are converted into milk, efficiency is 0.84. The evidence that K_M is applicable to work was obtained with sheep fed at several levels and walked on a treadmill.

When an animal starts to shiver, body fat and feed ME are convertible to heat (T). The incidence and extent of this demand is calculated from normal heat production, evaporative heat loss (E), live weight, the temperature gradient between animal and surroundings, and the insulation of tissues, pelage and air. Values of E and the last three items are given for sheep and cattle.

G is predicted from weight (and rate of gain in cattle). U is a function of stage of pregnancy and birth weight. L depends on milk composition. V is 0.81DE and, expressing intake in multiples of maintenance, P is 1.8% for unit increase in intake.

Application to Draught Animals

The ARC system is based on experiments with breeds of sheep and cattle used in temperate regions but, because it purports to represent biological reality, it should be equally applicable to all livestock if the appropriate parameters are used. Unfortunately many of them are not known for draught animals (Robinson and Slade 1974; Goe 1983).

Basal metabolism per unit metabolic body weight for a given mature animal may deviate as much as 20% from Brody's grand average on account of the animal's sex or species (Brody 1945; ARC 1980) or breed, being, for example, 10–20% lower in *Bos indicus* than in *Bos taurus* (Frisch and Vercoe 1976). As the causes of this variation are not known, B has to be measured in each species or class of animal with which the system is to be used.

Expenditure associated with locomotion is the same for diverse animals, including tropical draught cattle and buffalo (ARC 1980; Lawrence and Richards 1980). The ARC does not consider external work other than locomotion but all work generates heat (up to 8 times basal metabolism (Brody 1945) depending on type and rate of work, implement design, etc.) which should simply be included in W. Unfortunately no predictive formulae are available for this heat production; although it is found under laboratory conditions to be about four times the amount of external work done (Brody 1945, Boyne et al. 1981), the latter cannot be calculated either for farm work. However, Goe (1983) tabulates information for 16 species of animals and various types of work. There is no evidence whether expenditure divided by K_M predicts ME requirement for this work correctly.

All ruminants may well have similar efficiencies of feed utilisation (V and K) under "laboratory" conditions but climatic stresses (particularly heat), the presence of external or internal parasites (Steel 1974), disease and the performance of work probably cause appreciable variation. Thus, there is good evidence that the flow of residues through the gut, and hence digestibility, is affected by ambient temperature (Young 1982). Also, heat stress induces protein catabolism and cold stress fat catabolism, both of which impinge on the value of K (Armstrong et al. 1959). Data presented by the ARC suggest that K_G values for low quality forages, on which many draught animals subsist, may be substantially lower than given by the general predictive equations (e.g. 0.16 rather than 0.32 for digestibility of 0.50). Another problem with such feed is that the performance of several hours work daily must restrict intake by curtailing the time available for eating it and ruminating.

The efficiencies of non-ruminant herbivores are largely unknown for either laboratory or 'real life' conditions.

The ARC makes no allowance for the effects of hot conditions, indeed, to my knowledge no method of doing this has been proposed by anyone. This is unfortunate because many draught animals are exposed to hot climates. In general terms, when evaporative and sensible heat losses cannot dissipate the heat produced or absorbed, body temperature and, therefore, metabolic rate rise and appetite is reduced (Armstrong et al. 1959; Young 1982).

The formula for calculating milk energy content is universally valid and that for foetal energy may be. However, the energy values of weight gain or loss tabulated by the ARC are not generalisable because the fat content of weight change varies between genotypes as well as with stage of maturity; there are no data for draught animals.

Nutrient Supply

Animals shiver (perform internal muscular work) in the cold to promote heat production. This causes their energy requirement to increase and so they eat more feed. However, as their protein requirement is unchanged, reduction of the concentration of protein in the diet can be considered (Ames and Ray 1983). Performance of external work must have the same effect.

Again, if productive functions in working animals suffer because of the compulsory diversion of energy to the musculature, requirements for protein or other specific nutrients may diminish. On the other hand, processes that are not limited by energy supply, e.g. growth of pelage or body growth on nutrient-deficient diets, may respond positively when work results in greater intake of feed and whatever nutrients it provides.

Because biological reaction rates are sensitive to temperature, other effects on energy/nutrient balance may be mediated by changes in the temperature of rumen contents or body tissues. Changes of 1 or 2 degrees centigrade certainly occur as a result of 2–4 fold variation of heat production with feed intake diurnally and in the long term (author's unpublished observations). As heat production may be increased 8 fold during work (Brody 1945) and work is often performed under hot conditions, it is likely that protein catabolism in the rumen and in body tissues, and therefore protein requirements, will increase during work.

Thus there are several indirect effects of work that may or may not be significant but are not considered in the ARC or other feeding systems. Indeed it would be difficult for conventional systems to predict the balance of opposing influences; arguably, simulation modelling would be better.

Conclusions

The ARC system was designed for non-working sheep and cattle in temperate regions; a great deal of new data would be needed before it could be applied with equal confidence to draught animals of various species in the tropics. However, if energy expended in various types of work were known, this information could be combined with the best estimates of other parameters to allow operation of the system. Reasonable agreement between prediction and observation in a variety of situations would encourage general application but reasons for extensive disagreement would be difficult to identify because the real and conceptual systems are complex.

The British ME system, the American Net Energy system (NRC 1973, 1976) and the systems favoured in Europe (Alderman 1983) are fundamentally similar although they use different equations and data bases. Thus they would all encounter the problems discussed above in application to draught animals (see e.g. Robinson and Slade 1974). Older systems have largely been abandoned because they did not represent the biological events in sufficient detail, if at all, for diverse applications to be feasible or for causes of error to be traced. However, scarcity of sophisticated data may enforce consideration of an ad hoc approach to the feeding of draught animals.

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Genetics and Animal Breeding

Breeding Improvement of Draught Buffalo and Cattle for Small Farms

Charan Chantalakhana*

IN most developing countries in Asia draught animal power remains the most important source of energy input per unit of cultivated land area in spite of increasing use of petroleum-based power in some countries. In Bangladesh, India, Philippines, or Thailand, for example, the contribution of animal energy input per unit area ranged from 48 to 64% of the total energy input per hectare, contributed by human, animal, and mechanical sources (Table 1). From a socioeconomic viewpoint, the mixed use of all these sources of power in suitable proportions will offer the highest benefit to the farmers, especially those under rainfed agriculture conditions. Buffalo and cattle are the two most important draught animals in Asia (Table 2). Although the meat from buffalo and cattle is used for consumption in most countries listed in Table 2, it is quite clear that one of the primary objectives of the farmers in raising these animals is to obtain draught power as well as manure.

Table 1. Energy input from different sources for some selected countries of Asia (in kw/ha).

Country	Human	Animal	Mechanical
Bangladesh	0.111	0.208	0.006
India	0.059	0.149	0.037
Japan	0.082	0.000	0.937
Pakistan	0.089	0.186	0.182
Philippines	0.059	0.111	0.059
Republic of Korea	0.171	0.201	0.581
Sri Lanka	0.044	0.022	0.149
Thailand	0.059	0.164	0.119

Source: ESCAP Newsletter, Bangkok, Thailand.

DAP and Farming Systems

Buffalo and cattle raising has traditionally been integrated into crop production systems by Asian subsistence farmers, to provide draught power as well as manure and other products. By having crops and livestock together in an integrated farming system each crop or livestock could produce more due to the possible utilisation of wastes and by-products of each other (see Chantalakhana 1984). This and other similar advantageous features of integrated farming systems currently practised by most Asian farmers have been well recognised. Research and development in agriculture in Asia have to be based or started on the existing farming system foundation, because farmers and their available resources appear to be the most important factors that determine technological acceptance, and consequently agricultural development, under small-farm conditions.

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Table 2. Draught animal population in Asia (millions).

	Cattle[a]	Buffaloes[a]	Horses[b]
Bangladesh	35 070	1 644	0.05
Bhutan	306	27	
Burma	8 600	1 950	0.1
China	53 410	18 854	11.1
Democratic Kampuchea	956	404	
Democratic People's Republic of Korea	960	—	
India	182 000	61 500	0.86
Indonesia	6 435	2 506	0.6
Lao People's Democratic Republic	445	879	
Malaysia	540	293	
Mongolia	2 397	—	
Nepal	6 973	4 267	
Pakistan	15 084	11 794	0.5
Philippines	1 900	2 850	
Republic of Korea	1 531	—	
Sri Lanka	1 644	843	
Thailand	5 062	6 299	0.2
Viet Nam	1 765	2 378	

[a] Source: FAO Monthly Bulletin of Statistics, February 1983.
[b] Source: FAO Production Yearbook—1981, vol. 35 (1982).

Future Prospects

During the last two decades, farm mechanisation constantly increased at various rates in many Asian countries. This phenomenon raises questions concerning future use of DAP. But it was quite clear that the benefit of farm mechanisation on crop yield would be realised only when other production factors such as fertiliser, insecticide, irrigation water, etc. were available (Onchan 1983). It is therefore evident that under prevailing rainfed conditions and subsistence farming in Asia, farm mechanisation has not played a major role in crop production.

In the case of Thailand, the impact of farm mechanisation on production, employment, and income distribution remains unclear, and research findings are still inconclusive (Onchan 1983). The Thai government policy clearly reflects the importance of DAP as well as appropriate farm machinery. It stated '. . . Farmers in the poverty-stricken areas should have improved tools with human beings or animals as the source of power. Machinery with mechanical power should at the same time be further developed. These small machines are not meant to replace labour but will help facilitate and better the work . . .'

For Asia in general, in spite of an apparent increase in the use of farm machinery in certain areas, especially in irrigated areas, the use of DAP will remain proportionally high. It is also clear that there is scope for a choice of mix of power inputs. In many cases, DAP can be strengthened so as to be complementary to the mechanised system. In most situations there is no competition or conflict whatsoever between DAP and a mechanised system. In some countries such as Bangladesh, Thailand, Indonesia, or the Philippines, farmers often face the problem of draught animal shortage, which created serious concern with the government. Also on occasion administrative measures such as slaughter or export bans had to be implemented in order to improve such unfavourable situations. Recently, a Thai government program called 'Cattle and Buffalo Bank' was created to reduce the problem of draught animal shortage in rural areas.

Improvement of DAP

There are at least three aspects to be considered in improving or increasing DAP: (1) to increase the number of draught animals, (2) to increase quality of draught animals, and (3) to improve farm tool efficiency. These three aspects should receive proportionate attention in order to obtain maximum improvement of DAP.

The quality of draught animals can be improved by various methods such as better feeds and feeding, better management and care, disease and parasite prevention and control, as well as improved breeding and selection.

The objective of this paper is to present some aspects of genetic improvement of buffalo and cattle for draught with special attention to certain farming and husbandry practices of farmers under rural small-farm conditons.

Village Animal Production for Draught

Most of the Asian farmers are rural smallholders and have traditionally integrated their livestock and crop production. Most buffaloes and cattle are mainly raised for work in crop production. Their use for draught is quite suitable economically and sociologically since most farmers live in remote areas and own only small parcels of land, and family labour is available as needed. Buffalo and cattle production is not regarded as a distinct enterprise, but as a part of a crop production system. Many characteristics of this system are reflected in the husbandry practices and use of the bovine animals.

Feeding and Management

In Thailand, which is comparable to other Southeast Asian countries, village farmers usually set aside small plots of land for buffalo and cattle grazing to supplement other sources of grazing areas available in the village such as paddy fields, scrub forests on upland areas, highway shoulders, rice bunds, communal grazing lands, etc. In general, buffalo and cattle depend mainly on rice straw and stubble, while other crop residues such as corn stalks, cassava and kenaf leaves also provide substantial sources of roughage, especially during the dry season.

During the postharvest season, buffalo and cattle are allowed to graze in the paddy fields where breeding will also take place. When the summer season arrives, feed in the paddy fields becomes so scarce buffalo and cattle have to graze on highway shoulders or in upland scrub forests. At this time they will be supplemented with rice straw or other green fodders. Finally, when the rainy season comes and the cropping season begins, most areas will be under rice or other upland crops. Animals will be grazed only in fallow fields or the plots set aside for them. They are also tied around the household and fed with rice straw. No concentrate or mineral supplements are given. Animals are usually kept under the house during the night where they are reasonably safe from thieves. There are virtually no cash inputs used and most tending is done by family labour, mainly the children, women, or old folks.

Health care for buffalo and cattle is minimal. Some of them may be vaccinated against certain infectious diseases, but most are not. Farmers have little interest in bovine vaccination, except after a disease outbreak takes place. A common infectious disease in bovine animals is foot-and-mouth disease of Types A,O, and Asia-1. Haemorrhagic septicaemia is very serious in buffalo. Anthrax in both buffalo and cattle is not common. A small percentage of village cows are found to be positive for brucellosis. In addition, internal parasites such as *Strongeloides* and *Neoascaris* are also commonly found in both buffalo and cattle. In general, farmers do not buy any medicine to treat sick animals, preferring to use traditional curing methods. Some herbs and medicinal plants are also available in villages.

Breeding

Like all other Southeast Asian countries, in Thailand most village work buffaloes and cattle are the indigenous strains. Buffalo and cattle breeding generally takes place through random natural mating. Within-breed breeding is commonly practised in buffalo, with limited interest for crossbreeding of the swamp buffalo with the Murrah buffalo (milk type). Only very few farmers try to use the resultant crossbred buffaloes for draught. Some farmers complain about the difficulty in handling crossbred buffalo at work, but this could be attributed to the training of the work animals.

Crossbreeding of the indigenous cattle with the Brahman breed, through AI and natural mating, to produce larger and taller crossbred cattle for work and meat has been carried on during the last three decades in Thailand, as well as in other Southeast Asian countries. Draught cattle are used mainly for transportation such as carting, while buffaloes are used for ploughing in muddy fields. In Thailand, the male animals are preferred for work. Due to the shortage of draught animals, however, both the male and the female are used for work. The male buffaloes or cattle for work are generally castrated between 2 and 4 years of age, depending mainly on size and body conditions, before they are trained for work. Farmers select draught animals mainly on size, height, conformation, and other traditional outer appearances such as horns, positions of hair whirls, chevron, colour and markings, etc. Draught ability is believed to be related to body size and height. Farmers in Thailand prefer to breed their cattle to taller Brahman bulls, while the ideal low-set American Brahman is not the most popular type.

Castration of buffalo and cattle for work, in the long run, has a negative effect on animal body size since larger animals will be prevented from breeding around the age of 3–4 years. Shortage of good-quality breeding bulls has also been recognised as an immediate problem resulting from castration of buffalo and cattle in rural areas in Thailand. Castration of the males for work has also been observed to generate a higher degree of inbreeding in the village herds since more opportunity is allowed for a young bull calf to mate his own dam or sisters.

Selective breeding, except crossbreeding, has not been practised in village herds. Village farmers do not maintain a breeding bull since the number of breeding cows per holding is very small (2–3 head) in Thailand. Replacement heifers are usually produced within the farmer's own herd, while purchase of breeding cows is quite rare. As mentioned before, generally village buffalo and cattle breeding takes place during the postharvest season when the animals in the village, both males and females, are put together in the paddy fields where there is abundant feed supply and when the weather is cooler and dry (during November through January). Random natural mating takes place mostly during this period of time. Artificial insemination is also used but only 0.1–3% of the breeding cows are served this way annually. Average annual calf crops for village buffalo and cattle were reported to be 35–40 and 40–45% respectively (Chantalakhana 1983a).

Selection, Castration and Training

Selection of bovine animals for work by village farmers is commonly done when the animals reach 3–4 years of age. Selection is based mainly on size, height at wither, as well as general body development especially the forequarter. The other characteristics of animals which are taken into consideration by village farmers are: (1) feet and walking; (2) mouth, teeth and eating habits; (3) big broad brisket; (4) big long body; (5) broad straight back and big hump (in cattle); (6) horn size, shape, and setting; (7) neck and tail; (8) hair whirls; (9) skin thickness; (10) hair colours and markings; (11) temperament and behaviour.

Besides these characteristics, heat tolerance, disease resistance, and general adaptability of the animals are always included in the judgement of village farmers. However, no direct method for measurement of draught abilities of the animal is employed by farmers. The farmer owner of the animal will be able to observe its working abilities only when his animal is being trained for work, usually after castration.

Castration of bovine animals for work usually follows selection. In Thailand, 70–90% of work animals are castrated. Castration of cattle and buffalo is generally done by traditional methods, while conventional methods are also used. The most common traditional methods are (1) pounding of scrotum, (2) pounding on the neck of the scrotum, (3) pounding scrotum through a wooden clamp,

(4) splitting of scrotum with blade. A modern method is to use Burdizzo castrator, but this tool cannot be used to castrate buffalo and receives little interest from village farmers.

Training of buffalo and cattle for work is carried out after the animal has fully recovered from castration. There are generally three stages of training: (1) training with nose rope, (2) training with yoke and harness, and (3) training with special farm equipment. Nose-rope training facilitates handling and communication with the animal. The animal is trained to be accustomed to roping and signalling through rope pulling as well as human language, such as start, stop, left turn, or right turn, etc. Generally, nose-rope training requires about one month. The next step is yoke and harness training, when the animal walks according to determined directions, which depend on the type of work intended, either ploughing, carting, turning water pump, etc. At this stage two farmer trainers are generally required, one leading in the front of the animal and another controlling the rope from the rear. The animal will learn more about language, signals, as well as rope control of its owner. This step requires approximately 15-20 days. Finally the third step, special-equipment training, is when an animal, which has been trained for the first two steps, is put to work with a farm implement, such as plough or cart. For carting, which requires a pair of animals, a well-trained animal is commonly paired with a trainee animal. One farmer will lead the animals in front in order to train the animal to walk in a straight line, while another farmer, sitting on the cart, controls the animals. Afterward, the animals will pull the cart without the leader. Once a trainee animal learns carting work it will then be trained to get accustomed to actual traffic conditions. This step of training takes about 15-20 days.

Similarly, for ploughing, generally with single yoke for buffalo and with double yoke for cattle, a trainee animal is first led along a plough track by one farmer in front, while another farmer handles the plough and the animal from the rear. For double-yoke ploughing, a well-trained partner will be used to enhance learning. For single-yoke ploughing, of course, an animal has to learn individually. This process requires a period of 15-30 days.

After a work animal has completed training it will first be used for light work. Use of an animal for work will increase gradually with time. At about 5 years of age, the animal will be used for work to full capacity.

Work of Draught Animals

Although the paddy field is certainly a common place in Southeast Asia to find buffaloes and cattle at work, it is obvious, however, that the pattern and type of work for these animals varies from one country to another, and from one region to another. Buffaloes are mainly used for ploughing in muddy paddy fields, while cattle are preferred for carting. In some Southeast Asian countries such as Indonesia, Philippines, and Thailand, the animals are used for work approximately 2–4 months/year. In Thailand, they work most intensely during May–September involving ploughing, raking, puddling, as well as transportation (Buranamanas 1963). Most Thai buffaloes work for 5 hours/day, and each work buffalo ploughs about 4–5 acres/year. The average working life ranges from 12 to 15 years.

Breeding for Draught

In the first two sections, some village situations concerning draught animals breeding and husbandry practices as well as farming systems have been highlighted. It should be well understood at this point that systematic selective breeding of draught animals at the village level has been almost completely lacking in most Asian countries. As far as research is concerned, the same holds true, as reflected by Chantalakhana (1981a) and Goe and Hailu (1983). Except for a few experimental crossbreeding studies on a rather limited scale, of beef and buffalo breeds, not much direct breeding improvement of these animals has been done in Asia. In general, there are no specific breeding programs in Asia for draught animals.

Draught Abilities

The term 'draught' as used in agriculture refers to the force required to pull an object for a given distance (Goe and McDowell 1980). The tractive horsepower (hp) produced is calculated as:

$$\text{tractive hp} = \frac{\text{draught (kg)} \times \text{speed (km/hr)}}{270}$$

The measurement of animal draught abilities requires expertise in the field of agricultural engineering. In addition, it is well known that the draught of tillage implements, like a plough, is dependent upon such factors as weight of the plough, its shape, sharpness and scouring properties of the plough, angle of draught, character of the soil, skill of the ploughman, speed of travel, ambient temperature, and training of the animal. These factors complicate the accurate measurement of draught abilities of animals. This subject requires cooperation among animal scientists, agricultural engineers and crop scientists, as well as farmers. Research on improvement of draught animals would require an interdisciplinary approach, or preferably a farming systems research (FSR) approach. Without development of practical standards and tools for the measurement of draught abilities, a lack of information concerning these traits will continue to be a major hindrance to breeding improvement of draught animals.

Characteristics of Draught Animals

The ranges of averages of some production characteristics of the indigenous swamp buffalo in Thailand are presented in Table 3, while those of the indigenous cattle as well as of the Brahman and their crossbreds in Table 4. Some traits on working ability of the swamp buffaloes, which have been reported by few studies in Southeast Asia, are shown in Table 5.

It is obvious that very little information concerning draught ability of buffalo and cattle is available at present, while genetic information on these traits is almost completely lacking. This situation is not at all favourable to research in draught animal improvement. It is imperative that more research studies be supported to obtain information for the genetic improvement of buffalo and cattle for draught purposes.

In general it is believed that the working ability of an animal is directly related to its mature weight. Goe and McDowell (1980) stated that, under normal working conditions, a mature buffalo can develop a tractive effort of 10–14% of its weight. Body size and wither height appear to be very important criteria for selection when Thai village farmers look for a draught animal. The price of draught buffaloes or cattle is largely directly related to body size and weight at a certain age because the farmers can judge the animal's efficiency by these traits.

Table 3. Some characteristics of swamp buffaloes in Thailand.

Calf crop (weaned)	35–40%/yr
Calving interval	1.5 yr
Death loss (weaned calves & older)	2–3%
Death loss (birth to weaning)	10–30%
Replacement rate (cow herd)	6–7%
Age of cow at replacement	16–17 yr
Land use per A.U.	0.15–0.20 ha
Animals per family	1–4
Weight at birth	24–32 kg
Weight at weaning (8 mo)	90–120 kg
Weight of cows	350–440 kg
Weight of bullocks at maturity	500–550 kg
Age at first calving	4.5–5.5 yr
Dressing percent (bullocks)	45–50
Post weaning daily gain, grassfed bulls	0.24–0.30 kg
Finishing phase daily gain, feedlot steers	0.40–0.70 kg*
Area of land ploughed per day	0.14–0.15 ha
Days worked per year	60–120
Area of land ploughed/buffalo/year	1.6 ha
Average age of bullocks at slaughter	15 yr
Average years of work by buffalo	12 yr

Source: Chantalakhana 1983a.
* Same ration as cattle.

Table 4. Some characteristics of beef cattle in Thailand.

Calf crop (weaned)	40–45%/yr
Calving interval	1.5 yr
Death loss (weaned calves & older)	2–3%
Death loss (birth to weaning)	5–15%
Replacement rate	6–7%
Age of cow at replacement	15–16 yr
Land use per Animal Unit	0.15–0.10 ha
Animals per family	1–4
Weight at weaning (8 mo.)	
Native	80–100 kg
Crossbred, native/Brahman	100–150 kg
Brahman	130–180 kg
Weight of cow	
Native	175–250 kg
Crossbred, native/Brahman	300–425 kg
Brahman	450–550 kg
Age at first calving	
Native	4.5–5 yr
Crossbred, native/Brahman	4.5–5 yr
Brahman	4.5–5 yr
Weight of steers at maturity	
Native	375–425 kg*
Crossbred, native/Brahman	500–550 kg
Brahman	—**
Dressing percent, steers or bulls (hot weight)	
Native	45–55
Crossbred, native/Brahman	50–55
Brahman	—
Post-weaning daily gain, grassfed steers	
Native	0.20–0.24 kg
Crossbred, native/Brahman	0.30–0.40 kg
Brahman	0.35–0.40 kg
Finishing phase daily gain, feedlot steers	
Native	0.30–0.40 kg***
Crossbred, native/Brahman	0.35–0.60 kg***
Brahman	0.80–1.00 kg***

Source: Chantalakhana 1983a.
* Bulls castrated at 3 years of age.
** Not usually castrated.
*** 60–70% cassava chips, 10% corn, molasses and cottonseed meal.

Judging from field experiences as well as limited available research information on draught animal working ability, it would be advisable to genetically improve buffalo and cattle for draught based on their body weight and size at different ages. Table 6 shows the heritability estimates of some traits in buffaloes and cattle. In general, the rate of improvement through breeding methods concerning body weight or measurement (size) ranges from medium to high. In other words, genetic improvement of draught buffaloes and cattle is quite possible. While information directly concerning working ability is lacking, genetic improvement of body weight and size will be directly beneficial to farmers in Asia.

Table 5. Working ability of swamp buffaloes.

Maximum burden capacity	869 kg (female)
Draught power	287 kg (female) 370 kg (max)
Cart speed	50–57 m/min
Plough	0.05–0.08 ac/hr
Puddle	0.12–0.25 ac/pair
Work	20–146 days/yr

Source: Chantalakhana 1983b.

Table 6. Heritability of body weights and measurements in beef cattle.

	Estimates	
Traits	Beef cattle	Indian buffaloes
Birth weight	0.38	0.74
Weaning weight (6–8 mo)	0.30	0.43
Yearling wt or final wt	0.70	0.72
Mature weight		0.23*
Preweaning gain	0.27	
Postweaning gain (feedlot)	0.52	0.56**
Feed intake	0.44	
Feed conversion	0.36	
Weaning score or grade	0.16–0.65	
Yearling score	0.04–0.40	
Mature cows	0.42	
Body length	0.00–0.67	
Heart girth	0.06–0.71	
Wither height	0.41–0.57	

Source: Chantalakhana 1981a.
* Weight at first calving.
** Average daily gain from birth to 1 year.

Breeding Improvement

BREEDING GOALS

From socioeconomic standpoints of the existing agricultural production systems in Asia, breeding goals for the improvement of buffalo and cattle on small farms should be dual-purpose ones, either for draught-and-beef or for draught-and-milk, depending on farmer objectives. Breeding improvement which is aimed purely at draught ability might not yield maximum benefits to the farmers. When a dual-purpose goal is considered in genetic improvement of buffalo and cattle, then, the relationships between draught traits with beef or milk characteristics have to be taken into consideration in order to insure maximum overall breeding improvement. At the same time, as far as farmers are concerned, it is very important to know whether the resultant improved animals are suitable and acceptable under village small farm conditions.

Chantalakhana (1983b) discussed rather thoroughly breeding goals and approaches for the improvement of the swamp buffalo for small farms in Asia. Choice and suitability of various breeding goals including breeding for draught, draught-and-beef, draught-and-milk, as well as draught-beef-milk, were discussed.

GENETIC SELECTION

Although conclusive information on genetic variation of important traits concerning draught or beef in the indigenous buffalo and cattle is lacking, available evidence and experience indicates that within-breed or strain selection for draught and beef could yield considerable progress. It is highly recommended that national breeding herds should be organised in order to identify and multiply superior genetic quality stocks. Performance testing of buffalo and cattle bulls under the same specified environmental, feeding, and management conditions such as that going on in Thailand (Chantalakhana 1983b) should be implemented in each country.

The bulls should be tested for their performance under feeding and management conditions similar to those that exist in villages. Low quality and cheap supplement composed of locally available feedstuffs can be given in an appropriate amount to provide optimum conditions for genotypic expression. The main feed resource should be based on grass either through grazing or as silage. These animals should be put to test right after weaning (about 8 months of age up to 1 year). The test period should cover at least 240 days. Then, the breeding bulls can be selected at the end of the test based primarily on their weaning and final weights, while heart girth or body weight can be used as supplementary measurements.

The performance-tested bulls should be used for bull-loan programs in villages. The breeding cows in a bull-loan program should be tested for brucellosis or vaccinated against it, if possible.

Artificial insemination in village herds can be successful only through special projects or arrangements. Thus, a nationwide program should rely on natural mating because heat detection in buffalo and cattle and AI service effectiveness still remain as major problems in most Southeast Asian countries.

This breeding and selection method for the improvement of swamp buffalo and cattle for draught-and-beef should receive high priority in relation to other areas of research and development in buffalo and cattle production. It is strongly recommended that a nationally planned and coordinated breeding selection program for the swamp buffalo and cattle be initiated in every Southeast Asian country, where large buffalo or cattle populations exist, as soon as possible.

CROSSBREEDING

Crossbreeding in cattle, beef or dairy, has been quite common in Asia. Many exotic breeds have been introduced to cross with local indigenous animals. The Brahmans and Brahman crosses have been well accepted by village farmers in some countries. Use of Holstein-Friesian breeds for dairy crossbreeding is also quite common in most Asian countries. Intentional crossbreeding for draught, however, is not known. The Brahman crosses appeared to be preferred by the Thai farmers, as compared to the small indigenous cattle, when they were used for carting or transportation. Interviews with village farmers, who have had experience using both the indigenous and the Brahman crossbreds for draught, indicated that most farmers recognised the superiority of the crossbreds over the indigenous cattle.

During the past two decades there had been various attempts in different countries to cross the swamp buffaloes with the riverine breeds such as the Murrah in order to produce the crossbreds for draught, meat, and milk.

Reports on crossbreeding work in West Malaysia and the Philippines (although sample size was small) indicated satisfactory work performance of the crossbreds (Chantalakhana 1975). According to Liu (1978), about 45 000 crossbreds of swamp buffalo and Murrah had been produced in Southern China with the intention of producing more milk and meat, besides draught power. It was reported that the crossbreds were at least equal in heat tolerance to the local swamp buffaloes, and were superior in draught power, both in terms of speed and area per unit of time at ploughing (Table 7).

Table 7. A comparison of the ploughed area and ploughing speed by the 1/2 Murrah and local buffaloes.

	Ploughed area (mu)*			Ploughing speed (m/min)		
Group	Total area	Time used (hour)	Area/ hour	Starting	Middle	Final
1/2 Murrah	1.59	2.30	0.73	36.0	28.7	31.5
Local	0.96	2.03	0.48	28.5	25.1	18.1

Source: Liu Cheng Hwa 1978.
*mu = 1/6 acre.

Many reports indicated clearly the superiority of the crossbreds in milk production but information on their draught ability and acceptance by farmers has yet to be evaluated. De Guzman (1982) reported that, concerning buffalo draught performance, 39% of the farmers in certain regions of the Philippines rated the crossbreds poorer, 24% better and 14% equal, as compared with the swamp buffaloes.

Recently, in China and the Philippines, three breed crosses in buffalo, involving swamp, Murrah, and Nilli-Ravi, have been conducted in order to produce superior offspring for draught, meat, and milk. Preliminary results obtained so far are favourable.

However, as Chantalakhana (1983b) indicated, the performance of the crossbreds under village farm conditions needs to be evaluated. It should also be investigated that, when work buffaloes are used also for milk, what additional feed requirement is needed, and whether village farmers could provide that additional feed without negative socio-economic impact on other aspects of farm production. Only a very limited number of reports is available on nutritional requirements of cattle used for milk and draught.

At this stage of knowledge, it would be more appropriate to limit crossbreeding of the swamp buffaloes to the riverine breeds to an experimental scale only, until the above questions have been thoroughly investigated. Another caution on crossbreeding of the swamp buffaloes arises from the aspect of germplasm conservation, since little is known about genetics of the swamp buffalo.

Conclusions and Recommendations

The importance of DAP is well recognised by farmers and many who are closely concerned with agricultural production in Asian countries, but relatively little has been done to improve it. The first problem appears to be a lack of know-how in the fields of draught animal sciences as well as animal-drawn farm-tool technology. The second is a lack of real understanding and interest in DAP and small farmers among national administrators as well as researchers who are generally more accustomed to western technologies in agricultural production.

In order to be able to draw the attention of high-level national administrators, it is recommended that, first, an international or regional research network on DAP be established to provide leadership and catalytic action for researchers in different countries. At the same time a national coordinated research program on DAP should be organised or strengthened to focus on DAP improvement. It is advisable that a focal agency be made the secretariat office of the national DAP research program. It will be quite beneficial if the DAP research program links in some way to the FSR activities or institute. An interdisciplinary approach and multiagency involvement in the DAP research network are recommended.

Besides research, training and demonstration on DAP technologies and their contribution to small farm agricultural production are also very important. Farmers, extension workers, educators, and other key village personnel should be encouraged to participate in some DAP training activities. Also, DAP technologies should be included as a part of college or university courses, wherever possible.

Last but not least, it is recommended that a national or international organisation such as FAO, UNDP, or ACIAR should play a leading role during an initial stage of the development of the DAP network, in order to bring DAP into national as well as international focus.

As stated by McDowell and Hilderbrand (1980), failure to implement agricultural development programs which integrate both mechanisation and animal traction will continue to result in inefficient use of resources to enhance agricultural production. This is especially the case on small farms where capital resources are limited. This fact has to be said and repeated again and again, it has to be demonstrated again and again, until it is well understood and fully appreciated by high-level government administrators. Otherwise, DAP improvement will remain a subject of talk but not of action.

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Genetic Requirements for Draught Cattle: Experience in Africa

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IN sub-Saharan Africa, about 12 million draught cattle are used. Of these, half are used in Ethiopia, where most farmers use Ethiopian Zebu oxen for ploughing. In Botswana, also, most farmers use draught animal power, but in most other countries, a large proportion of farmers cultivate with hand tools. Where draught cattle are used, they are generally castrated bulls, weighing less than 350 kg, and they are most commonly used in pairs. Nearly all the draught cattle of Africa are indigenous breeds, and they either come from the small herd of the farmer, or are purchased from other farmers or pastoralists. In either case, the animals are seldom bred primarily for their draught qualities, since the cattle are an integral part of complex farming and social systems.

In most countries in Africa, draught animal power has been used for less than 60 years, and it is now being increasingly used and promoted. It is often being actively encouraged in the context of agricultural development projects supported by donor agencies. Many expatriate and local personnel responsible for running or advising on such projects are under the impression that the local cattle breeds are unsuitable for draught purposes, and so there is a tendency to propose schemes for utilising new genotypes through selection, crossbreeding or the introduction of different breeds or species. In some cases, research stations have attempted to evaluate such options, although frequently the numbers of animals involved have been very small.

The available literature on the genetic requirements for draught cattle is very limited, and bibliographies on animal traction in Africa contain few, if any, references on the subject (IEVMT 1980; Goe and Hailu 1983; Bartlett and Gibbon 1984). Although the available published material is referred to in this paper, most of the information will be based on my personal experience of visiting animal traction programs in many countries. The approach adopted here is based on the knowledge that many people in both national programs and aid agencies are recommending policies of adopting new genotypes for animal traction, and it is therefore designed to stimulate discussion in the key area of defining genetic priorities for draught animal programs in Africa.

Selection Criteria

Whether one is selecting individual animals for work, or whether one is selecting breeding stock for producing future generations, it is necessary to define the characteristics of an outstanding draught animal.

The most important characteristic for the farmer, which can easily be overlooked, is the ability to survive in the prevailing environment. The death of a draught animal can be a disaster to a farming family. The draught animal must be able to withstand the prevailing climate, and cope with the local pathogenic challenges using the feed resources available to the farmer, and requiring only such services as are both available to, and affordable by, the farmer. The characteristics relating to survival are precisely those which have been selected by farmers and by nature over very many years, and have resulted in the highly adapted indigenous cattle breeds found in the different regions of Africa.

In West Africa, the Small N'Dama is both trypanotolerant and resistant to streptrothicosis (Starkey 1984), and several hundred thousand N'Dama and other taurines are used in Senegal, The Gambia, Guinea, Sierra Leone, southern Mali, Ivory Coast, Burkina Faso, Togo, Ghana and Benin. To the north of the tsetse zone, the larger Zebu is generally preferred. Around the boundary of the main trypanosomiasis area, some farmers use the large Zebu animals, and accept a certain risk of mortality, while others prefer to accept the lower draught power of the taurines, and so gain the advantages of higher security through greater survival potential. In limited geographical areas, farmers compromise and use Zebu × taurine crossbreeds, but south of the main tsetse boundary zone, farmers almost invariably use taurine work

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animals, even when Zebu cattle are available from herds destined for the meat trade.

Trypanotolerance is only one example of a survival characteristic, and most indigenous African breeds have evolved a degree of resistance to local tick-borne and infectious diseases. In addition most indigenous breeds are well adapted to the local climatic conditions, and many research studies have shown that *Bos indicus* breeds are better able to withstand high temperatures, water shortage and tick challenges than the classic *Bos taurus* breeds developed in Europe. Such adaptive characteristics appear to be particularly important in draught cattle which are subjected to the stress of physical work.

The principal survival characteristics will depend on the prevailing biological, physical, social and economic environment, and as the environment improves, so the importance of survival characteristics may be modified with time. For example the provision of trypanocidal drugs, or specific vaccines by veterinary services, may reduce the importance of genetic trypanotolerance or disease resistance. However genetic survival characteristics should not be lightly abandoned, given the potentially ephemeral nature of veterinary services.

The second generalised characteristic is the ability to work effectively within the prevailing environment. This is not a single feature but a complex interaction of different criteria, for it is not simply strength that is required, but the ability to provide the necessary work output in the available time, under the prevailing ecological, social and farming conditions.

Body size and strength are of particular importance in determining maximum working power and the two are closely related. In a review of work in francophone Africa it was considered that power output depends on a wide range of factors characterising the animals and their environment, but sustained animal traction was primarily related to body weight, being in the order of 10–15% of body weight (CEEMAT/FAO 1972). When draught cattle walk fast, maximum instantaneous effort is approximately equal to body weight, but it is nearer 50–70% of body weight if animals are moving at their normal speed (CEEMAT/FAO 1972). In horses clear correlations have been established between body mass and strength (Dryendall and Bengtsson 1984). While it is clear that the larger animals have greater absolute strength, relative draught capacity actually decreases with body size, so that smaller animals are stronger, relative to their weight than larger animals (Lawrence and Mathers 1985).

As large animals are stronger, they can pull larger implements, thus reducing the time required to undertake operations, and reducing the distance the farmer has to walk behind the implements. Large animals are also able to make more efficient use of poor quality forage (Lawrence and Mathers 1985). Thus size is particularly important in selecting for work output, for example in log pulling operations in Malawi.

The selection requirement is not simply for work output, but for work within the prevailing climatic, agricultural and socioeconomic environment. Thus large animals may not actually be desirable. Larger animals require more food, are more expensive, and farmers may prefer to reduce the risk of loss of all their capital in a single accident or disease occurrence by having two smaller animals rather than one large one. Smaller animals may have a higher reproductive potential than larger ones, and where animals are an indicator of wealth and are used in traditional transactions, absolute numbers are often more important than their size. Thus there may be significant social and economic pressures in favour of small animals, rather than large ones.

Moreover, it must be stressed that even the smallest taurine breeds of West Africa, which stand just 1 m at the shoulder and weigh only 200 kg, can be useful draught animals, provided the equipment used is designed for their size. Small animals can be used in pairs or, as in Botswana, they can be linked together in teams of up to 16 animals, to provide sufficient power to pull large ploughs or carts. Thus, while work output is an important selection criterion, this need not necessarily imply selection for large size.

The third general criterion for selection is conformation. There appears to be broad agreement on desirable physical attributes for draught animals, and these have been described by many authors, including Williamson and Payne (1959), CEEMAT/FAO (1972), Howard (1979), Watson (1981) and Reh (1982). It is generally agreed that draught cattle should look powerful, compact and strong, with well-developed muscles, particularly in the hindquarters (CEEMAT/FAO 1972) or forequarter (Howard 1979). The chest should be broad and deep, the neck strong, and the hooves hard. Short stocky build is preferred for ploughing, whereas larger legs are preferred for transport operations. Reh (1982) considers a hump desirable, while Goe (1983) argues that it is not necessary and can be undesirable if it encourages the use of withers yoking systems. Where head and neck yokes are used, horns are important for securing the yoke.

The fourth main criterion is that the animal should be of appropriate temperament, not too wild and certainly not lazy. Williamson and Payne (1959) recommend against the early rejection of animals showing fierceness and nervousness, since this may indicate a useful degree of spirit and courage.

The fifth group of characteristics represents compatibility with other requirements of the farming system. As many animals have multipurpose functions they may be required to have adequate milk production, reproductive ability, quality of carcass and hide, and even valued aesthetic features such as colour and length of horns.

Evaluation of Performance

Having established basic selection criteria, it is necessary to assess individuals and, where practicable, to objectively measure the extent to which the desirable characteristic is exhibited. Unfortunately there appear to be few, if any, standardised performance testing procedures for draught cattle. In Europe standardised tests have been developed in an attempt to assess the maximum efficiency and draught aptitude of horses (Dryendall and Bengtsson 1984). Such assessments have involved ergometers, loaded carts, obedience tests and measurements of heartrate, respiration and sweating. However the FAO Expert Consultation on Draught Animals (FAO 1982) concluded that sophisticated performance-testing stations would not be appropriate in Africa, where selection would involve relatively small, widely dispersed herds.

The lack of any standardised, objective measurement of trypanotolerance was stressed by Karbe and Freitas (1982). There are similar problems with measuring other forms of disease resistance and environmental adaptation. There appear to be no objective measurements of draught animal temperament in use in Africa, although draught animals are frequently rejected following subjective assessment of temperament. Work output is frequently measured in various ways on research stations, but there has yet to be developed a standardised system to give a reliable measurement that relates to the requirements for power within the farming systems. In contrast, the anatomical features of cattle are relatively easy to measure. However, it should be noted that during 25 years of measuring and assessing the conformation of draught horses, the only characteristic that statistically correlated with draught capacity was liveweight (Dryendall and Bengtsson 1984). Although easy to measure, liveweight may not necessarily be a characteristic for selection.

Heritability

The phenotypic characteristics of a good draught animal result from the interaction of the genotype and its environment. Heritability is a measure of the proportion of variation between individuals in a population that can be ascribed to the genotype. If the heritability is high, a high proportion of the variation in a population can be attributed to the genotype, and the phenotype is therefore a good indicator of the genotype, and so selection should result in rapid genetic progress. If heritability is low, the variation between individuals is primarily a result of environmental effects, and selection of good phenotypes may not necessarily indicate that good genotypes are being selected. It is therefore important to know what draught characteristics have high heritability.

The FAO Expert Consultation on Draught Animals (FAO 1982) concluded that 'the heritability of draught traits seems to be fairly high.' Certainly the heritability of final body weight in cattle is well quantified and high, at around 0.6 to 0.7 (Preston and Willis 1976). A useful historical example of genetic selection for large size is seen in the development of the massive draught breeds of Europe. At a time when pure beef breeds, such as the Aberdeen Angus, were being selected for tasty fat, the Charolais and Chianina were being selected for draught power, with a large frame, high body weight and a high proportion of muscle. Changing consumer tastes and the need for improved efficiency have more recently made these 'draught' characteristics of value in European beef production systems.

The heritability of survival characteristics such as trypanotolerance is not well defined (Schote 1982). The heritability of other draught characteristics has also not been reliably estimated. However, in horses, heritabilities are considered high, as illustrated by the high prices paid for stud fees, and it may be noted that selection for racing horses, though emphasising very different characteristics from those of draught cattle, involves a combination of anatomical, physiological and behavioural characteristics.

Genetic Improvement of Indigenous Breeds

I am unaware of any large-scale systematic attempts to breed for draught characteristics among the indigenous breeds of Africa. However, in Togo, one such scheme is being started using Brougou, Zebu and N'Dama types. While the scheme involves government ranches, the animals are being kept as far as possible under the conditions of husbandry and disease challenge typical of village situations.

The FAO Expert Consultation on Draught Animals (FAO 1982) recommended that mass selection techniques be used for draught characteristics, and that selection be carried out within the environment in which the animals work. Mass selection involves the performance testing of individuals and the selection for breeding of the animals which excel. However the organisational problems associated with the recommendations are formidable. Firstly, objective systems for measuring performance at village level have yet to be adequately developed. Secondly, as cattle are seldom maintained exclusively for draught, selection will probably have to be multi-factorial, using some form of weighted values. Thirdly, the nearly universal practice of castrating draught bulls will make mass selection among the majority of working animals an impossibility. Where animals are castrated, family selection may be possible, but the small family size of cattle in Africa makes rapid progress unlikely. Fourthly, the fact that draught characteristics are generally assessed relatively late in life, makes the generation time long, and makes natural progeny tests very difficult. Finally, when genetic progress is achieved by selection, genetic dissemination systems will have to be developed to allow small farmers, each owning very few cattle, to benefit from improved genotypes.

This is not to suggest that within-breed improvement is impossible. On the contrary, despite all the constraints, excellent multi-purpose draught breeds like the Ethiopian Zebu, the Africander and the N'Dama have been produced over generations of traditional selection, without quantified performance tests. Modern techniques of measurement and data recording should make possible much faster rates of progress than that achieved in the past, but this will require a high degree of organisation (and by implication funding), and a long time scale for significant improvements to be made in indigenous populations.

Introduction of Purebred Exotic Animals

In view of the primary requirement for draught animal survival, it would seem unwise to attempt to introduce purebred exotic animals into villages for draught animal use. Nevertheless, in Africa this is frequently recommended by visiting consultants and aid agencies. For example, the introduction for draught purposes of water buffalo and exotic *Bos taurus* breeds has been seriously proposed for both Liberia and Sierra Leone, countries with serious animal health problems and limited veterinary resources. Such suggestions, if taken up, would have confounded a new technology with a novel genotype, and could have led to the rejection of the technology through the use of inappropriate breeds. Apart from the dangers of mortality, introduced purebred animals would inevitably be both expensive and in short supply for many years. Thus any introduction of purebred animals should be seen in a very long timescale, if it is anticipated that smallholder farmers in villages are to benefit from the exotic breeds.

It may be noted that while the water buffalo has proved to be a highly successful draught animal in Egypt, it has not generally thrived in sub-Saharan Africa. It has been introduced in small numbers at various times into several African countries (FAO 1977), but to date there has been no significant expansion of its population at village level in sub-Saharan Africa.

Crossbreeding

There are many advocates of using crossbreeds of indigenous and exotic breeds for draught purposes in Africa. For example, ILCA (1981) cited this method as a major means for improving the efficiency of animal traction in Africa. The principle is generally to combine the larger size of the exotic breed with the adaptive characteristics of the indigenous breeds.

Crossbreeding for draught would be particularly effective if the exotic animals themselves were viable in the villages. If this were the case an upgrading program could produce higher and higher grades, using exotic bulls, until the population would comprise mainly the exotic genotypes. However this situation does not appear to have been recorded in relation to draught animals in sub-Saharan Africa.

In the majority of cases, the exotic animals are not well adapted and so there is a constant problem with maintaining the optimal balance of genes within the village populations. If crossbred F_1 animals are bred among themselves, they will tend to produce some animals that are effectively higher grades (and therefore unadapted) and some which are lower grades (and relatively unproductive), with little control over genetic balance. To use a backcross with the indigenous breed is most realistic, under village conditions, but genetic progress is consequently reduced. In ranches, or in very large herds, rotational crossbreeding can be used to prevent the production of unadapted grades, but this is not practical under normal village conditions.

An example of a crossbreeding program for multipurpose requirements with draught characteristics specified and assessed, involved the crossbreeding of N'Dama with Jersey in Ivory Coast (Letenneur 1978). The 3/8 Jersey 5/8 N'Dama were found to be very suitable for draught purposes, and were reasonable milk producers, but unacceptably high mortality was experienced wherever the percentage of Jersey genes exceeded 50–

60%. Thus the crossbreds could not be confidently produced under village conditions, and it was necessary to supply appropriate crossbreds from a controlled breeding station, and these were subsequently backcrossed with the adapted N'Dama in the villages. As the products of breeding stations are inevitably expensive, and the system was not self-sustaining at the village level, the scheme was unable to expand to make a major impact on the local population, as had initially been hoped.

Almost all countries in Africa have some crossbreeding scheme involving exotic dairy animals and indigenous breeds. There have been several attempts to evaluate the crossbred male 'by-products' of such schemes for draught purposes. One example, in Kenya, demonstrated that crossbred Friesian × Zebu animals were larger and more powerful than the local East African Zebu but that the smaller indigenous animals could actually perform all the required draught operations quite adequately. Thus the excess power of the crossbreds was unnecessary, and the fact that they required greater maintenance feed was a very severe disadvantage (Tessema and Emojon 1984). Indeed feed supply, rather than genetic potential for power, was the major limiting factor, and in the particular year of the trials up to 50% of the draught cattle in the villages around the station died of starvation. It was therefore concluded that the larger crossbred animals were not appropriate in the farming system of that area of Kenya.

In a few cases, crossbreeding schemes have attempted to create new breeds. In Senegal, there are records of breeding research specifically aimed at creating a new draught breed (Hamon 1971). However the number of animals involved was small, and farmers continued to use the local Zebu animals, so that a decade after the breeding program, little evidence remained of the scheme. In Madagascar, a multipurpose draught breed, the Renitelo, was developed from Limousin, Africander and the Madagascar Zebu. However as the Renitelo animals were larger and therefore more expensive than the local animals, most smallholder farmers continued to use the smaller, cheaper Madagascar Zebu (Tran van Nhieu 1982).

Conclusions

In general in Africa, draught animals are used by farmers constrained by limited resources, and for whom minimisation of risk is a major consideration. They therefore require animals that can survive well in the environment. They also require animals that are relatively inexpensive, easily available, and which are easy to sell and replace in the event of a serious injury at a crucial time in the farming calendar. Farmers also require animals that are appropriate to their socioeconomic conditions. Absolute draught power may sometimes be important, but it is not the primary consideration, particularly as, with appropriate equipment and harnessing systems, even the smallest of African cattle breeds can be used effectively for work. It is therefore concluded that in the majority of cases, the local indigenous cattle breeds will be most appropriate, and it may be noted that most of the successful draught animal programs in Africa have, indeed, been based on traditional breeds.

It would seem universally agreed that the vast majority of animals maintained under traditional systems of management never attain their genetic potential in size, being constrained mainly by nutrition and disease. In general, indigenous animals maintained on research stations are significantly heavier, and more powerful, than comparable animals in the villages. It is therefore concluded that there is very great scope for increasing the available power from indigenous breeds by systems of improving management. In the light of the very great organisational constraints to selecting for draught, given the lack of defined selection criteria, the dispersed animals and the castration of bulls, it would seem that scarce resources could be better used in improving management, nutrition and health, rather than attempting to achieve genetic improvement.

Crossbreeding specifically for draught would not appear to be a priority in the vast majority of farming systems. Where a crossbreeding program is being undertaken for milk/meat/multipurpose functions crossbred animals may be usefully employed, provided they are adequately adapted, and provided sufficient feed resources are available.

If a national breeding or selection program exists, or is contemplated, draught characteristics could be included in the selection criteria, provided appropriate performance tests are developed. However rapid genetic progress cannot be expected except in the case where a change in body weight is desirable. Where such selection is undertaken, it should, as far as possible, be performed under the environmental conditions in which the draught operations are required.

In the light of the existing adaptation and suitability of the indigenous cattle breeds for draught work in Africa, it is concluded that appropriate genetic requirements for draught are generally available. Thus resources should be concentrated on maximising the existing potential, rather than on developing new breeding programs.

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Genetic Improvement of Buffalo for Draught Purposes

J. E. Vercoe*, J. E. Frisch*, B. A. Young† and I. L. Bennett*

TOTAL amount of draught power from buffaloes may be increased in a number of ways:

1. Increasing numbers—by increasing net reproductive rate.
2. Increasing liveweight—implying either an increase in mature size or an increase in growth rate, or both. (This has as a corollary an improvement in nutrition.)
3. Increasing heat tolerance—to allow increased hours of work.
4. Decreasing the draught load—to reduce heat load.
5. Increasing the power output—independent of liveweight.
6. Controlling parasites and diseases—to reduce mortality and morbidity.

Although there may be scope for the genetic improvement of (1), (5), and (6), discussion has been restricted to the improvement of (2) and (3).

In considering the role and possible impact of genetic improvement on draught power output of buffaloes, it is essential to realise that with the existing infrastructure, the time scale before any national goals would be achieved is of the order of 25 years. This estimate depends on the immediate implementation of crossbreeding and it would be considerably longer if improvement was attempted by within-breed selection.

Breeding goals must therefore be geared to perceived needs 25 years hence rather than conditions that exist today. Farm size is a significant factor to consider in this regard for it will influence whether animal power will be required at all for land preparation. Currently the arable land per farm in many Asian countries is less than 3 ha and the proportion of farms with less than 1 ha is around 70% (Anon. 1983). In Bangladesh there are marked differences in farm size and the use of draught animals between areas of high and low population densities (de Lasson 1981). The relationship between population and farm size suggests that farm size will decrease throughout Asia as population increases and this will be associated with a decline in draught animal power required per farm. A similar phenomenon occurs in Africa (Collinson 1984).

Thus strategies for genetic improvement of draught buffaloes that could be used by smallholders should be geared towards a future situation of small arable areas perhaps less than 0.5 ha, and a limited supply of available feed. These strategies may not be applicable to buffaloes used for road haulage, although some may be relevant.

The Approach

In an attempt to understand the problem and develop goals for genetic improvement that could be relevant to conditions in 25 years time, a simple model was constructed (based on a cattle model by B. A. Young and G. Godby, unpublished data) that allows the assessment of the relative effect on draught output of factors such as body size (liveweight), draught load and speed, heat tolerance and climatic conditions. The potential rate of increase in rectal temperature was the parameter used to evaluate the effect of these variables.

The model is illustrated in Fig. 1. Heat inputs to the animal are the sum of the endogenous sources of heat (fasting, feeding at maintenance, normal activity) and the heat produced by the work of walking and pulling a load. The efficiency of these components has been assumed from Procter et al. (1934), Blaxter (1962) and Brody (1964). The two avenues of evaporative heat loss are based on values for buffalo from the literature (Moran 1973; Chikamune 1983); cutaneous, 160 g/m^2; respiratory, 20 g/m^2. Sensible heat loss was calculated from the surface area and the difference between skin and black globe temperature (Kuehn et al. 1970). The model is driven by the variables liveweight, draught load, and speed; skin, globe, and air temperatures; and wind speed. The increase in rectal temperature (ΔT_r) is presented as °C/hour. Because the model is

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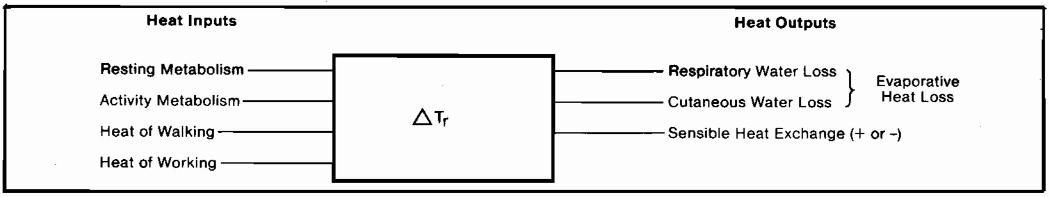

Fig. 1. Diagram of the model to assess the effect of liveweight, work and environment on buffalo.

'static' rather than 'dynamic' the increase in rectal temperature calculated by the model of a working animal is overestimated and ΔT_r should be viewed as an 'instantaneous driving force' rather than an actual value for the rise in rectal temperature for a particular set of conditions. However, validation of the model using the results of Moran (1973) for buffalo standing in the sun and exercising indicated that the estimates from the model are not unrealistic, are comparative, and are sufficiently encouraging to allow the use of the model to illustrate some important considerations for further research, and to define possible breeding goals and/or management strategies.

Like all models this one has its limitations, particularly those associated with extrapolation from a point in time when both the physiological reactions of the animal to environmental conditions and the environmental conditions themselves are changing.

Results

A variety of loads, speeds and environmental conditions were tested at two liveweights (300 and 500 kg) to investigate the potential effect of differences in liveweight on ΔT_r.

Effect of Liveweight

The effect of liveweight per se, at the same cutaneous and respiratory evaporative heat loss (per m^2) and when the animal was fed at maintenance, depends on the difference between skin temperature (T_s) and globe temperature (T_g). When ambient temperature (T_a), T_g and T_s are such that the convective heat flux is negative, the 'instantaneous driving force', ΔT_r, is lower for the smaller animal but when conditions are such that the convective heat flux is positive the larger animal has the lower ΔT_r. Thus, if animals of 300 kg and 500 kg are standing in the sun early in the day, ΔT_r is lower for the 300-kg animal, but later in the day it is lower for the 500-kg animal (Table 1). However, the effect of liveweight per se on the rate at which ΔT_r increases is negligible.

Effect of Load

The effect on ΔT_r of varying the load, keeping speed constant, is illustrated in Fig. 2 for different environmental heat loads (1000 h and 1400 h).

As might be anticipated, increasing the load causes a greater ΔT_r in the smaller buffalo. Increasing the environmental heat load increases ΔT_r by a

Table 1. Calculated changes in 'instantaneous driving force' (ΔT_r) in two buffaloes standing in the sun at different times of the day.

	ΔT_r (°C/hr)			
Time	300-kg			500-kg
0800†	0.4			0.7
1000	1.3			1.4
1200	2.3			2.1
1400	2.4			2.3
1600	1.9			1.8
†Conditions:	T_a °C	T_g °C	T_s °C	Wind m/sec
(See text for explanation of terms)				
0800	26.4	36.6	31.0	1.7
1000	28.5	39.6	34.0	2.2
1200	31.5	43.5	34.0	2.0
1400	32.6	44.1	36.0	2.1
1600	32.7	41.9	35.0	2.0

From Finch et al. 1982.

constant amount for each animal but the amount is greater for the smaller animal. It can be deduced from Fig. 2 that where the load is a similar proportion of liveweight, ΔT_r is similar for both sizes of buffalo. Load is thus a major determinant of the heat load on the animal and, consequently, of ΔT_r.

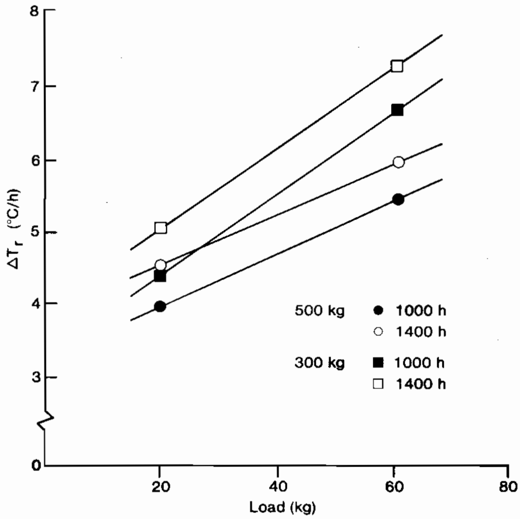

Fig. 2. The effect of draught load on 'instantaneous driving force' (ΔT_r) of a 300- and a 500-kg buffalo working at 0.85 m/s. Assumed conditions at 1000 and 1400 h: T_s 34 and 36 °C; T_a 28.5 and 32.6 °C; T_g 39.6 and 44.1 °C; wind speed 2.2 and 2.1 m/sec, respectively. Respiratory and cutaneous water losses, 20 and 160 g/m^2 for both animals.

Effect of Speed

When the load for each size of buffalo is kept constant (50 kg), increasing the speed has a greater effect on ΔT_r in the smaller buffalo. This is illustrated in Fig. 3 for different environmental heat loads estimated at 1000 and 1400 h. Increasing the environmental heat load increases ΔT_r by a constant amount for each animal but the amount is greater for the smaller animal.

Combined Effects of Load and Speed

Because both load and speed are variables that determine work output it is possible to estimate, for a given load, a speed for a smaller buffalo at which ΔT_r is similar to that for a larger buffalo. For example, if a 300-kg and a 500-kg buffalo were each required to pull a load of 50 kg, the smaller animal travelling at a speed of about 0.76 m/sec would have a similar driving force on T_r (5.6 °C/hour) as the 500-kg animal travelling at 1 m/sec. This may well be the order of magnitude of the difference in 'normal' walking speed between a 300- and a 500-kg animal. However if the two animals are required to walk at the same speed, ΔT_r of the smaller animal increases to 6.8 °C/hour.

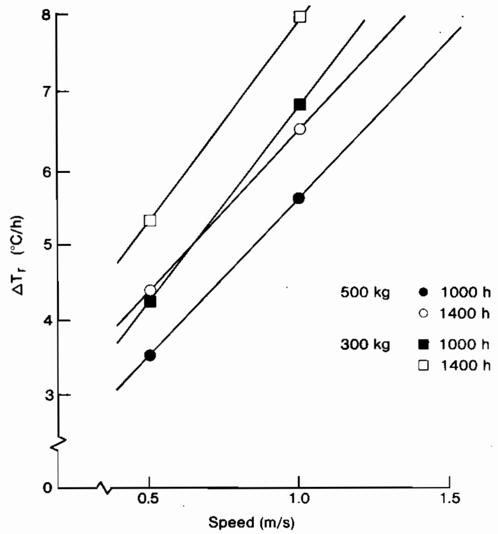

Fig. 3. The effect of speed on ΔT_r of a 300- and a 500-kg buffalo pulling a 50-kg load. The conditions at 1000 h and 1400 h are those for Fig. 2.

If a 300-kg animal can pull a 50 kg load with a similar ΔT_r to that of the larger animal, albeit travelling more slowly, the relative areas tilled, assuming a furrow width of 15 cm, would be 0.054 and 0.041 ha/hour for the larger and smaller animal, respectively. Alternatively, it would take a 500-kg animal 18.5 hours to till 1 ha compared to 24.3 hours for a 300-kg animal.

Effect of Shading

The best estimate of environmental heat load is the black globe temperature (T_g) since it measures the combined effects of radiation and wind speed. Shading a black globe reduces the magnitude of the temperatures used here by about 16% (Bennett et al. 1985). The relative driving force on T_r in buffaloes of different sizes working in the sun or shade is shown in Table 2. The assumptions are that the buffaloes are working at the same speed with loads of 10% of their liveweight and the estimates refer to typical 1000 h and 1400 h environmental conditions. The model predicts a marked difference in ΔT, if some device could be developed, such as a shade that would enable the T_g at which the buffalo is working to be reduced.

Effect of Evaporative Cooling

If total evaporative water loss could be increased by 20%, which may be possible by selection, the

Table 2. Calculated changes in 'instantaneous driving force' (ΔT_r) for buffaloes of different weights working at the same speed (load 10% of liveweight).

Time	Liveweight	ΔT_r (°C/h) Sun	Shade*	Δ Evaporative cooling**
1000	300	4.99	3.60	4.60
	500	4.99	3.25	4.68
1400	300	5.62	3.88	5.23
	500	5.49	3.60	5.08

* T_g reduced by 16%.
** In sun but evaporative cooling increased to values of 24 g/m^2 for respiratory and 192 g/m^2 for cutaneous losses.

driving force on T_r is reduced by about 10% as indicated in Table 2. The effect is similar for the two sizes of buffalo.

In the model the effects of increasing total evaporative water loss and reducing T_g would be additive but in reality there would be an interaction between the two avenues of heat flux, the magnitude of which is unknown.

Effect of Wallowing

The effect of wallowing cannot be estimated from this model. However Chikamune (1983) recently demonstrated that wallowing at 25 °C for 20 min reduced T_r by about 1 °C from an initial value of 40.7 °C.

Discussion

The comparative information generated by this model suggests alternatives for the improvement of draught power output of buffaloes. Although we have been asked to pay particular attention to those elements where genetic improvement may be possible it is necessary to get these into perspective.

We have taken as our central argument that heat tolerance, coupled with the low level of nutrition available to meet maintenance and work requirements, is a major limitation to the performance of an otherwise healthy buffalo.

In an ideal nutritional environment the bigger the draught animals the better. In the Asian situation, where farm sizes are small, and getting smaller, and there are few prospects for dramatic short-term improvements in the level of nutrition, attention needs to be focused on finding ways for more efficient utilisation of smaller draught buffalo.

The major advantage of the smaller animal is its lower feed requirement for maintenance. When it is considered that a buffalo may work for only 10–30% of the year (Chantalakhana 1983), the lower maintenance requirement assumes greater significance. Where suitable facilities are available it may be possible to identify individuals within a weight class that have low maintenance requirements and use them for breeding purposes. This would eventually increase the efficiency of maintenance without reducing liveweight.

The only disadvantage of the smaller animal is its reduced power and work output. This disadvantage could be partly overcome by increasing both its heat tolerance and its power output per unit of liveweight.

Improving heat tolerance by selection within a breed of buffalo would be a very slow process and the gains, in terms of extending the length of ploughing time, are relatively small. The model illustrates that if evaporative cooling could be increased by 20% it would reduce ΔT_r by only about 10%. In addition, there is a lack of facilities for identifying animals of superior heat tolerance and this, coupled with the difficulties of multiplying and disseminating such animals, suggests that this approach is of doubtful priority. A more realistic approach may be to crossbreed to a superior genotype. However the extent of the variation in heat tolerance between breeds or strains, even between such diverse types as the Murrah and swamp buffalo, is not known. As an immediate step further research on and development of improved methods of frequent sprinkling could be justified. Perhaps covering the animal with wet sacking or other material may offer a technique which simulates the effect of an increased sweating rate in terms of the effect on ΔT_r.

In view of the prediction that radiant heat load is relatively important in determining ΔT_r, two managerial options are available to minimise this effect. The first is to ensure that the main work activity occurs in early morning or late evening. The second is to devise a shade, attached in some way to the harness, which protects the animals from the direct solar radiation load. The combined effect of shading and wetting in reducing ΔT_r and extending ploughing times could be worthy of investigation. The model, which treats these as additive effects, suggests that reductions in ΔT_r of about 50% are possible.

Prospects for increasing the efficiency of power output by genetic means are no better than those for improving heat tolerance. Rather, reducing the draught load and/or speed would appear to offer the most significant and immediate avenue of improvement. There is now considerable evidence that demonstrates the marked effect that improvements in harness and implement design can confer on draught output (Garner 1958; Sarkar 1981; Sarker and Farouk 1982). For example it has been estimated that, with traditional implements, eight tilling operations may be necessary for good land preparation but with improved implement design this can be reduced to four (Sarker and Farouk 1982). Thus, although a smaller animal will take longer to work a given area, this is relatively unimportant if improved implements enable a 50% reduction in total working time. Similarly, the use of improved harness has been shown to increase draught output by about 25% (Garner 1958). These sorts of increases cannot be matched by any genetic improvement of draught or power output. Implementation of these improvements, which present sociological rather than technological difficulties, would make the use of smaller animals for draught a more viable proposition than if traditional practices continue. The use of locally available materials in the manufacture of new harnesses and implements requires further investigation and promotion.

The prospect of combining improvements in draught power with an increase in milk production has not been covered in this paper. In some areas of Asia such a combination is already required and in other areas it is a potential future requirement. Since future needs for draught are likely to be focused on a small buffalo any increase in milk production should also be achieved without an increase in size. Crossbreeding to Murrah or Niliravi breeds, whilst producing an increase in milk production, will also increase size. Consequently some effort should be made to identify breeds or strains of buffaloes that are smaller and more heat tolerant than these riverine breeds but have a higher milk yield than the recognised swamp types. Identification and evaluation of potential candidate strains that fulfil these requirements should be considered a priority area.

Conclusions

1. Reduction in farm size and reduced availability of feeds suggests that future draught power requirements will have to be met by smaller rather than larger buffaloes.
2. The inherent lack of heat tolerance in the buffalo is accentuated in small animals working in hot environments and drawing heavy loads.
3. Genetic improvements in the draught capacity of buffaloes should focus on the identification of breeds and strains that are relatively heat-tolerant, low in maintenance requirement and resistant to parasitic and other diseases, with a view to crossbreeding.
4. Further developments in harness and implement design should favour an increased usage of smaller animals.
5. Management strategies that decrease solar radiation load and/or increase evaporative cooling should be investigated for both their effectiveness and feasibility of use under practical conditions.
6. We agree with the recommendation of Chantalakhana (1983) that direct selection for increased draught capacity is a relatively low priority area for resources in view of the urgency for short-term improvements in draught power.
7. Identification of smaller breeds that are more heat-tolerant than riverine types but have higher milk yields than swamp varieties should prove useful for future crossbreeding programs.

Acknowledgement

We wish to thank Mr C. R. Holmes for assistance in modifying and running the model.

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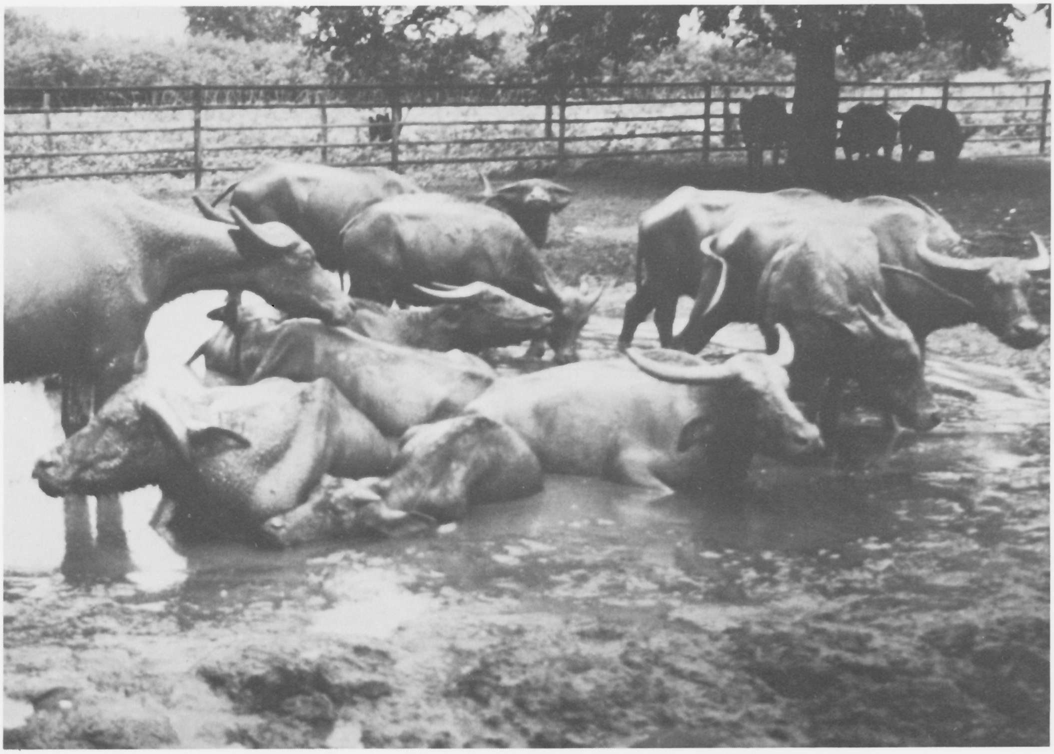

Reproduction and Health

Reproduction in Draught Animals

Vicente G. Momongan*

In most Asian countries, draught animals play an important role in farm operations. They are the main ally in the daily activities of smallholder farmers in almost all developing countries in Asia. About 80% of the farmers in Asia and the Pacific Region have only manual and/or animal power available to them in their farming operations.

About 51% of the power needs of Asian farmers is provided by animals; 26% by human; and 23% by mechanical power. It has been estimated that nearly 400 million oxen, buffalo, horses, donkeys, camels, elephants, etc. provide this power and contribute to half of the energy the Third World farmers use today (Khan 1983).

Of the various draught animals, buffaloes and cattle are the main sources of power for the various farm operations. They have become an integral part of the traditional village farming systems. They are widely used to plough, harrow, level land, puddle rice fields and thresh rice; pull carts, sledge and logs; press oil from seeds and extract juice from sugar cane; and serve as riding or pack animals. With increasing costs for fossil fuel and mechanised farm implements, the use of draught animals will remain part of smallholder farming systems for a long period of time.

The aim of this paper is to present information on how reproduction in animals is affected by their being used for draught. There are few references to this work in the literature. While it is true that a number of studies on reproductive parameters of some draught animals like cattle, buffalo, horse, etc. were done, they were measured without relating them to their being actively used as draught animals. Ideally, two groups of animals should be studied on a long-term basis with respect to their various reproductive traits, with one population being actively used for draught and the other group not being used for work. With the same management and other environmental conditions, the differences in the attainment of the various reproductive traits between the two groups may be attributed to the imposition of using the animals in one group for draught.

Thus, the data that will be presented in this paper may only have an indirect bearing on how the imposition of work may affect reproduction. Since among draught animals, buffaloes and cattle are the main ally of the smallholder farmers in their various farm operations, emphasis of the study is on these two species of farm animals. However, in some parts of Asia like India, camels, horses, mules, donkeys and yaks are used as draught/pack animals, but no data have been reported in the literature on reproduction.

Reproduction and Production Traits of Cattle

The Umblachery, Hallikar and Khilari are known as typical Indian draught breeds; and the Sahiwal, Tharparkar and Red Sindhi as typical Indian dairy breeds of cattle (Bhat 1979). No study has ever been done to investigate the effect of using the cattle for draught on its reproductive traits. Thus, the most that we can do is to look at some of the reproductive traits between dairy breeds of cattle which are not ordinarily used for work and the draught breeds of cattle in India.

Table 1 shows that the age at first calving, service period and calving interval are much longer in draught cows than in non-draught cows. The crossing between the Indian dairy breeds with the exotic breeds (*Bos indicus* × *Bos taurus*) greatly reduced the age at first calving, service period and calving intervals of the crossbred cows as compared to those of the draught breed cows. It may be stipulated that the delay on the age at first calving of the draught breed cattle could be due to genetics which means that they may be genetically late maturing as compared to the dairy breeds. It should be borne in mind that in India, cows are traditionally not used for work, but only the bullocks. The delay in service period and calving interval could be due to a

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Table 1. Reproduction and production traits of draught and dairy cattle of India.*

	Daily milk yield (kg)	Lactation length (days)	Age at first calving (months)	Service period (days)	Calving interval (months)
Typical Indian draught breeds					
Umblachery	0.70	233.7 ± 9.1	45.6 ± 1.1	202.0 ± 8.9	16.1 ± 0.4
Hallikar	0.90	285.1 ± 10.1	45.1 ± 1.5	298.3 ± 7.5	19.7 ± 0.9
Khilari	1.00	255.0 ± 3.1	51.5 ± 1.1	175.0 ± 4.0	15.2 ± 0.2
Typical Indian dairy breeds					
Sahiwal	3.80	283.5 ± 1.8	40.2 ± 1.8	156.0 ± 3.2	15.0 ± 0.6
Tharparkar	3.70	280.1 ± 6.0	49.4 ± 0.4	145.5 ± 8.3	14.8 ± 0.8
Red Sindhi	3.70	384.0 ± 2.4	41.7 ± 0.6	146.8 ± 5.1	14.7 ± 0.3
Typical Indian dairy crossbreds					
Red Sindhi × Friesian	6.3	283.8 ± 8.3	29.2 ± 0.6	90.0 ± 10.8	12.2 ± 0.4
Red Sindhi × Red Dane	6.2	267.0 ± 9.4	28.3 ± 1.2	71.0 ± 10.3	11.7 ± 0.4
Red Sindhi × Jersey	3.7	305.8 ± 7.2	29.0 ± 0.9	109.6 ± 9.9	13.6 ± 0.5
Sahiwal × Friesian	5.7	294.6 ± 5.1	34.7 ± 6.8	133.6 ± 11.5	13.7 ± 0.4
Sahiwal × Jersey	6.7	314.0 ± 16.8	32.6 ± 0.6	120.0 ± 15.4	13.3 ± 0.6

* Adapted from the report of Bhat (1979).

number of things: (1) postpartum anoestrus may have been longer in draught breeds than in dairy breeds of cattle; (2) mating may have been deliberately delayed in draught breed cattle, whereas, in dairy breed cattle, early mating is essential since milk production is desired; and (3) the incidence of embryonic mortality could be higher in draught cows than in dairy cows.

Reproduction of Swamp Buffaloes

Of about 3 million carabaos (swamp buffaloes) in the Philippines, 98.5% are in the hands of smallholder farmers (Castillo 1981). A survey conducted by de Guzman and Perez (1981) revealed that of 540 carabaos owned by 354 farmers in Luzon, 47% were castrated bulls, 30% were cows, 8% were heifers, 8% were bulls, 4% were heifer calves, and 3% were bull calves. Seventy-seven percent of the farmers used carabao power in all their farming activities whilst none had a purely mechanised operation. Eighty-six percent of the farmers used machines in only 24% or less of their farm work. Of the draught carabaos raised by farmers, 63% were males and 37% were females. The bulls were castrated at the mean age of 3.3 years, ranging from 1.8 to 4.8 years.

Recently, 807 female carabaos raised primarily for draught by 716 smallholder farmers in Pampanga, Nueva Ecija, Quezon and Tarlac were subjected to rectal palpation to determine the reproductive status of the ovaries and uterus. The history of each animal was obtained from the owner at the time of rectal palpation and the nutritional status of each animal was scored according to the following system:

Score 1: Animal is in very poor condition, very thin with prominent scapula, hip and pin bones, and ribs;
2: Animal in poor condition but relatively better than those in score 1;
3: Animal in good condition with hip and pin bones, and ribs discernible but not prominent;
4: Animal in much better condition with well-covered hip and pin bones and clean-cut barrel indicating well-fleshed ribs;
5: Animal in excellent condition but not fat;
6: Animal in overfat condition with all bony prominences well-covered with fat.

Results shown in Table 2 indicate that the percentages of nulliparous and multiparous carabaos examined were 45.1 and 54.9, respectively. The mean age (± SD) of carabao heifers examined was 5.3 ± 2.6 years (range = 2–16 years). Because most heifers had previously exhibited oestrus, these fig-

Table 2. Breeding history of carabaos submitted for examination.

Location (Province)	Number of animals examined	
	Nulliparous	Multiparous
Pampanga	80	81
Nueva Ecija	51	107
Quezon	155	145
Tarlac	78	110

ures should not be interpreted as the age of puberty. The mean age of carabao cows was 9.2 ± 3.4 years (range = 4–22 years). According to breeding histories of 427 carabao cows, the mean number of calves born per female was 2.1.

Based on rectal diagnosis, pregnancy percentages were 30.0 and 25.3 at Pampanga in February and September, 29.1 and 10.7 at Nueva Ecija in April and September, 6.1 and 15.5 in November and March at Quezon and 16.0 at Tarlac in April. Over 85% of the pregnancies were less than 6 months. In the Philippines, the breeding season of carabaos is usually from August to February. The causes for the low pregnancy rates (Table 3) could be attributed to farmers submitting only those carabaos that they doubted or suspected of being pregnant, preventing the breeding activities of working female carabaos by tethering them and the high incidence of anoestrus or failure to detect oestrus.

Of the 143 pregnant carabaos, 43% were primiparous, with mean age of 4.9 ± 1.9 years (range = 2.5–12 years). They were estimated to calve at a mean age of 5.5 ± 1.8 years. For 82 multiparous cows, the calving interval was calculated as 26.3 ± 12.2 months (range = 11.5 to 57.5 months).

Table 3. The incidence of pregnancy in carabaos maintained under smallholder conditions.

	Pampanga	Nueva Ecija	Quezon	Tarlac
No. examined	161	158	300	188
No. diagnosed pregnant	44	27	42	30
Pregnancy rate (%)	27.3	17.1	14	16

The ovarian status of non-pregnant carabaos (Table 4) showed that acyclic buffaloes (n = 210) had reproductive disorders such as dormant ovaries—normal sized ovaries lacking in follicles or CL (56.7%)—comprising 14.7% of the total population palpated (n = 807), cystic ovaries (18.1%) representing 4.7% of the total population, infantile ovaries (21.9%) making up 5.7% of the entire population, and abnormalities of the uterus and cervix (3.3%) representing only 0.87% of the whole population. The 431 cycling females comprised 44.5% heifers and 55.5% cows. The total distribution of reproductive disorders in heifers and cows was similar (49 versus 51%). However, the occurrence of infantile ovaries was observed only in heifers. Since the average age of heifers with infantile ovaries was 3.3 ± 0.7 years (range = 2–5 years), puberty is apparently delayed in carabaos used for draught under field conditions.

Table 4. Ovarian status of non-pregnant carabaos under smallholder conditions.*

	Heifers	Cows
No. examined	303	361
No. in oestrus	8	15
No. cycling	192	239
No. acycling	103	107

* Based on rectal palpation; cyclic = palpable follicle or corpus luteum; acyclic = no palpable ovarian structures.

Body scores indicated no differences in the nutritional status of heifers (3.16) and cows (3.14) with an overall mean score of 3.14. However, the body condition score was significantly influenced ($P < 0.01$) by the location of the animals. The average body scores reflecting body condition of carabaos in Pampanga, Nueva Ecija, Tarlac and Quezon were 3.41, 3.21, 3.20 and 2.89, respectively. These differences in body condition may be the sum effect of the variability as regards feeding, management, draught utilisation and other husbandry practices in these locations.

The body scores of pregnant carabaos (3.38) were significantly higher ($P < 0.01$) than those of non-pregnant animals (3.10). The mean body score of non-pregnant animals was also lower than the overall mean body score (3.14) of carabaos in this study.

Nutritional status as reflected by body scores had a profound effect on cyclicity of the carabao. Cyclic animals had significantly ($P < 0.01$) higher body scores than acyclic animals (3.18 versus 2.94). The body scores of cycling heifers (3.21) were higher but not significantly different from those of cycling cows (3.16). Acyclic cows had a higher body score than acyclic heifers. However, the difference was also not significant (2.97 versus 2.91).

A survey was conducted by de Silva et al. (1985) on the indigenous buffalo of Sri Lanka to determine the systems of their management, patterns of utilisation and reproductive performance and the interrelationship among these factors. The sample comprised 11,863 buffaloes belonging to 528 holdings distributed in 16 of the 24 districts of the country. Buffalo farmers were visited, a questionnaire administered and stock numbers were physically verified. Rectal examination was done on 1300 breedable females in the sample in order to determine their reproductive status.

The results indicated that the buffaloes were managed extensively (free grazing only) or semi-extensively (tethered with or without free grazing). The main source of feed consisted of low quality herbage obtained from grazing. Paddy straw was fed in some regions during periods of fodder shortage. No concentrate feed supplementation was provided. The average herd size per holding was 22.5

ranging from 5.3 at Kandy to 53.6 at Hambantota district. On average a herd was composed of 17.1% of 0–1 year, 13.0% of 1–2 years, 9.1% of adult heifers, 32.9% of cows, 14.9% of castrated bulls and 13.1% of entire bulls.

About 92% of the farmers used their buffaloes in land preparation for paddy cultivation and 82% used them also in threshing the harvest. The mean age of initial use was 3.1 years and 82.9% of the farmers used both male and female buffaloes for draught. The mean duration of work was 52.3 days/year.

Only 14% of the farmers milked their buffaloes regularly and the number represents only 1.3% of the buffalo cow population. The overall mean lactation yield was 1.5 litres/day with a lactation length of 5–6 months. Rectal examination revealed 56.5% pregnant, 17.4% not pregnant but cycling and 26.1% not pregnant and acycling. The mean age at first calving was 45.7 months and the average calving interval was 18.9 months or 567 days. These variables were, however, found to vary significantly among districts, agroecological zones and according to systems of management and utilisation. Fertility was found to be comparatively higher in milking, limited suckling (calf separated during part of the day) and non-working groups of buffaloes than in draught buffaloes.

Haemorrhagic septicaemia and gastrointestinal parasitism were reported to be the major disease problems. Percentages of annual mortality were 25.4, 21.5 and 8.0 among age groups of 0–1 year, 1–2 years, and adults (above 2 years), respectively.

In Indonesia, Toelihere (1980) presented a survey conducted by him in 1977 which covered seven provinces and 560 farmers. He noted that a typical farmer has only 1.74 ha of rice field and 1.16 ha of dry land to support an average family size of 6.98. Most of the farmers (87.6%) owned their buffalo and 12.4% owned by partnership. On the average, 88% of the farmers used their buffalo for rice field cultivation, and according to 76.9% of the farmers, the animals are used for work only in the morning. However, during planting seasons the animals work in the morning and afternoon especially in West Java (30.2%) and in East Nusa Tenggara (38.1%). The number of buffaloes owned by the farmers ranged from 1.8 head in Central Java to 14.1 head in South Sulawesi with an overall mean of 6 buffaloes per family. It should be noted that in Indonesia the buffaloes are used in pairs for draught.

Usually the animals are herded to graze the whole day (64%) when they are not working. The herding is entrusted to the farmer's son (52.6%) or to others 34.6%). The farmers breed the female buffalo at an average age of 3.76 years, and if we assume a gestation period of 320 days, the estimated age at first calving is 4.64 years or 55.68 months. However, 62.3% of the farmers would not know which bull has mated his cow. Mating occurs mostly after harvest period when all the animals are let loose on pasture.

The absence of bull was claimed to be the frequent cause of reproductive failures in Central Java (45.0%), Bali (31.3%), South Sulawesi (20.5%) and North Sumatra (20.45%). On the island of Bali, 17.5% of the farmers do not allow their buffalo cows to mate because they believed that pregnant animals cannot perform well in their work.

Age at First Calving and Calving Interval

On the average, the age at first calving of swamp buffaloes is about 10 months longer as compared to that of riverine buffaloes (Table 5). Wide variations occur within types. This is due to differences in management, nutrition, degree of selection or genetic quality of the herd/breed or individual and other environmental factors. While it is true that in general the swamp buffaloes are used for draught and the riverine buffaloes are not, it is difficult to deduce how much 'draught' has contributed to the delay in its first calving. Genetics could play a

Table 5. Age at first calving of riverine and swamp buffaloes.

Location	Reference	Reported mean age at first calving (months)
River		
Sri Lanka	Jalatge and Buvanendran (1971)	56.50
Sri Lanka	Lundstrom et al. (1982)	52.00
India	Krisnamacharyulu and Prabhu (1973)	40.29
India	Kanaujia et al. (1974)	42.70
India	Raut et al. (1974)	48.00
India	Lall (1975)	41.97
India	Johari and Bhat (1979)	32.40
India	Reddy and Mishra (1980)	40.00
India	Sastry et al. (1981)	61.70
Italy	Roy Choudhury (1971)	36.70
Egypt	Oloufa and Stino (1979)	38.00
Pakistan	Chaudhary and Ahmed (1979)	47.07
	Average	44.78
Swamp		
Thailand	Usanakornkul et al. (1979)	60.00
Thailand	Chantalakhana et al. (1981)	57.60
Philippines	Subere (1978)	54.00
Philippines	Momongan et al. (1984)	63.60
Malaysia	Camoens (1976)	54.50
Malaysia	Jainudeen (1983)	47.00
Sri Lanka	de Silva et al. (1985)	45.70
	Average	54.63

major role in the onset of puberty and subsequent age at first calving. Momongan (1984) reported that published heritability estimates of age at first calving ranged from 0.230 to 0.784 or an average of 0.541. The swamp buffaloes, through the years, may not have been selected for prolificacy, but perhaps for its size and strength. It should be noted, however, that the data reported by Jainudeen (1983) were the calving interval of the institutional herd of swamp buffalo at MARDI which are not used for draught. On the other hand, the report of de Silva et al. (1985) was derived from indigenous Lankan buffaloes which are generally small. They mentioned the fact that the mature weight of Lankan buffaloes rarely exceeds 320 kg. On the other hand, the swamp buffaloes in Thailand, Philippines and Malaysia may attain mature weight of 404–600 kg, 364–545 kg and 364–565 kg, respectively (Chantalakhana 1981).

The calving interval of swamp buffaloes is much longer than that of riverine buffaloes (Table 6). Again the difference could not be wholly attributed to the fact that swamp buffaloes are primarily used for draught, whereas the riverine buffaloes are not. No doubt genetics play some role in the attainment of this production trait. However, the heritability estimates of first calving interval, as reported by Bhat (1979), was only 0.009 ± 0.037, indicating that environmental factors may play a much greater role in the expression of this trait. Indeed, calving rate has been observed to be very variable, depending on the management systems used, the nutritional conditions of the animals, the type and breeding of the animals, climatic conditions and other factors.

Table 6. Calving interval of riverine and swamp buffaloes.

Location	Reference	Reported mean calving interval (days)
River		
Sri Lanka	Jalatge and Buvanendran (1977)	551.0
Sri Lanka	Perera (1981)	514.0
India	Kanaujia et al. (1974)	497.6
India	Lall (1975)	457.0
India	Gurnani (1976)	434.0
India	Kanaujia et al. (1976)	430.1
India	Johari and Bhat (1979)	479.5
Pakistan	Chaudhary and Ahmed (1979)	530.0
Bulgaria	Polikronov et al. (1977)	443.0
	Average	481.8
Swamp		
Thailand	Mongkonpunya (1978)	621.0
Thailand	Chantalakhana et al. (1981)	584.9
Philippines	Subere (1978)	510.0
Philippines	Momongan et al. (1984)	726.0
Malaysia	Camoens (1976)	651.0
Malaysia	Bakar (1980)	448.0
Malaysia	Jainudeen (1983)	532.0
Australia	Ford (1981)	465.0
Sri Lanka	de Silva et al. (1985)	567.0
	Average	567.2

Other Reproductive Traits

A number of studies have been published on various reproductive traits of the buffaloes such as oestrus cycle, oestrus duration, ovulation time, postpartum oestrus, gestation period, gestational oestrus, and others which were reported in a compendium by Momongan (1984) and Mohan (1984). In general, there is not much difference in oestrous cycle, oestrus duration, ovulation time and gestation period between swamp and river-type buffaloes. However, the riverine buffaloes are much better milk producers than the swamp buffaloes (4–6 vs 1–1.5 litres per day).

Summary and Conclusions

Draught animals will continue to play an important role in agriculture, especially in the various operations of smallholder farmers. However, there is a dearth of information on the effect of using the animal for draught on its reproduction. Limited information in this area of work can be found in literature on draught cattle and buffaloes. However, on other draught animals like camels, donkeys, mules, yaks and elephants, there is practically no information in the literature on reproduction.

Indian draught breeds of cattle are older at first calving, and have a longer service period and calving interval than Indian dairy breeds or crossbreds of exotic dairy breeds. Similar trends were observed in buffaloes. The riverine buffaloes (dairy breed) are younger at first calving and have a shorter calving interval than the draught swamp buffaloes.

Surveys on the reproductive efficiency of the buffaloes raised by smallholder farmers revealed low pregnancy rates in buffaloes which are mainly tethered as compared to those which are allowed to graze freely in groups. Also, the cycling and the pregnant female buffaloes have better body conditions than those which are acycling or not pregnant.

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Reproduction in Draught Animals: Does Work Affect Female Fertility?

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CATTLE and water buffalo are the most common domesticated species used for draught in many Asian countries. Traditionally, males are preferred because of their larger body size and greater working capacity, but in some countries females are used for work because they could also produce calves and milk. Although much effort has been devoted to the mechanical aspects of draught power, information on the effects of work on the reproductive process of either cattle or buffaloes is limited. Perhaps this may be attributed to the practice of castrating males for easier handling and tractability. On the other hand, if breeding females are used for draught purposes it is important to ascertain the impact of work stress on female fertility so that measures could be taken to prevent a decline in calf crop.

Thermal stress, particularly in a tropical environment adversely affects female reproduction either directly or indirectly through a reduction in feed intake and secretion of reproductive hormones. The extent to which heat generated during work affects the chain of events leading to ovulation, conception, pregnancy, fetal development and parturition is not known. Clearly, a better understanding of the female reproductive process of draught animals is necessary in developing management systems which will not depress lifetime productivity in terms of calf crop and milk.

This paper will briefly highlight the unique features of female reproduction of Zebu cattle (*Bos indicus*) and water buffalo (*Bubalus bubalis*), then focus attention on the stages of the female reproductive cycle which are vulnerable to thermal stress and inadequate nutrition, and finally indicate areas for future research which could lead to the development of potentially useful methods for alleviating reproductive disorders in the draught cow and buffalo.

Female Reproduction

Over 95% of cattle and water buffaloes in Asia are reared by smallholder farmers under suboptimal conditions of management and nutrition, with suckling being an important practice for milk letdown and nutrition of the growing calf. Most draught males are castrated at maturity, leaving young males to mate indiscriminately.

Zebu Cattle

Zebu cattle reach puberty and sexual maturity at a much later age than temperate cattle (*Bos taurus*). The modal length of the oestrous cycle is 20 days. Oestrus is shorter and of lower intensity than in temperate breeds. Gestation length and interval from calving to first ovulation are longer than for *Bos taurus* breeds (Table 1).

Water Buffalo

Water buffalo, like cattle, are polyoestrous and breed throughout the year. However, seasonal calving patterns, reported in many countries, have been attributed to ambient temperature, photoperiod and feed supply (Ahmad et al. 1981). Puberty or first oestrus occurs at 15–36 months depending upon the nutritional status of the animal (Table 1). The oestrous cycle of the buffalo is about 21 days with ovulation occurring after the end of oestrus or 18–45 hours from the onset of oestrus. Overt signs of oestrus are less obvious than in cattle. The most reliable sign of oestrus is the acceptance of the male. Oestrus which lasts 17–24 hours commences during late evening with peak sexual activity occurring during the night. Although matings do occur during the day, the intensity of sexual activity is usually depressed. The length of gestation and the postpartum intervals to first oestrus and ovulation are longer in buffalo than cattle.

Female Reproductive Disorders

As there is no economic necessity to maintain breeding records at the smallholder level, many farmers use only the number of calvings, calves born, or weaned as criteria of reproductive efficiency. Under this system a cow or a buffalo produces on the average two calves every 3 years.

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Table 1. Female reproductive characteristics of Zebu cattle and water buffalo (adapted from the literature).

Parameter	Cattle		Water buffalo	
	Mean	Range	Mean	Range
Age at puberty (months)	19	14–24	21	15-36
Oestrous cycle				
Length (days)	20	15–28	21	18–24
Oestrus (hours)	12	6–18	21	17–24
Ovulation				
Time from onset of oestrus (hours)	25	16–35	32	18–45
Gestation length (days)	290	285–295	315	305–330
Age at first parturition (months)	40	24–72	42	16–60
Calving interval (months)	16	13–19	18	15–21
Postpartum interval to:				
Uterine involution (days)	36	30–42	35	16–60
First ovulation (days)	60	30–120	75	35–180
Conception (days)	154	50–258	180	40–400

Long calving intervals are a feature of female infertility in Zebu cattle and buffaloes in Asia. Both postpartum anoestrus and repeat breeding make significant contributions to these extended intervals.

Postpartum Anoestrus

Postpartum anoestrus is a state of ovarian acyclicity occurring during the suckling period in many mammalian species. Normally, ovarian activity is reestablished in milked cows within 30 days postpartum (Lamming et al. 1981). On the contrary 30–40% suckled Zebu cows and buffaloes experience an extended postpartum period (Jainudeen 1984). The absence of oestrus results from a failure in the resumption of ovarian cyclicity (true anoestrus) and not, as previously believed, from a failure of oestrus detection (apparent anoestrus). The endocrinological basis of postpartum anoestrus is not fully understood although suckling, lactation, high ambient temperature and nutrition are known to influence the condition. The additional stress of physical activity may further aggravate the condition. Thus the economic impact of postpartum anoestrus could be considerable particularly in draught females.

Repeat Breeding

A repeat breeder cow exhibits normal signs of oestrus every 18–24 days but requires more than three services to become pregnant. The time at which a cow returns to oestrus after breeding gives some indication as to the time at which an embryo died. If embryonic death occurred before day 16 of the cycle in cattle, the corpus luteum regresses as in a normal cycle causing no extension of the cycle. If, however, the embryo died later, regression of the corpus luteum is delayed until remnants of embryonic tissues are resorbed. The animals will then experience extended cycles. In cattle, because most embryonic deaths occur between the period of hatching of the blastocyst and implantation (days 8 and 16 of pregnancy), cycle lengths are unaffected (Diskin and Sreenan 1980). The cause(s) for loss of about 50% of the embryos during the first three weeks of pregnancy in repeat breeder cows are obscure although several factors have been suspected.

The incidence of repeat breeding is higher in Zebu cattle and buffaloes following artificial insemination than natural service. Errors in oestrus detection may also contribute to repeat returns to service in Zebu cattle (Sharifuddin et al. 1983).

Factors Affecting Female Fertility

Thermal stress, inadequate nutrition, suckling and disease may be among the major factors adversely affecting female fertility in draught cows and buffaloes in a tropical environment.

Thermal Stress

Exposure of most animals to elevated ambient temperatures results in reduced reproductive performance, particularly in the tropics where thermal stress prevails during most months of the year. Although some of the reduced fertility can be attributed to male infertility such as reduced libido and poor semen quality, much of the infertility is due to the effects of heat stress on female reproduction, particularly from oestrus to implantation (Jainudeen 1976).

Thermal stress alters the length of oestrous cycles, reduces the duration and the intensity of oestrus, and if the heat stress is severe, will induce anoestrus in the cow (Bond and McDowell 1972). High environmental temperatures depress fertility of cows (Stott and Williams 1962) by increasing the incidence of fertilisation failure and embryonic mortality. High ambient temperatures at the time of breeding and for 72 h thereafter had a detrimental effect on conception (Dunlap and Vincent 1971). High atmospheric temperature on the day of and the day after insemination was inversely associated with fertility (Gwazdauskas et al. 1973). An elevated temperature-humidity index prior to breeding was associated with a linear decline in fertility (Ingraham et al. 1974). Heat stress reduces fetal growth in late gestation and conceptus function which may have carry-over effects on lactation and postpartum reproduction (Collier et al. 1982).

Information on the effects of thermal stress on buffalo reproduction is limited. During summer when ambient temperature and photoperiod were at their maximum, prolactin levels were highest (Kaker et al. 1982) and plasma progesterone levels were lowest (Rao and Pandey 1982). About 28% of all reproductive failures in over 12 000 buffaloes under Indian village management were attributed to non-functional ovaries particularly in summer and autumn (Rao and Sreemannarayanan 1982).

Inadequate Nutrition

In general, any nutritional regime which results in loss of body condition is likely to be associated with reduced fertility in cattle and buffalo. If the level of nutrition is such that a lactating cow or buffalo loses body condition during the first 60 to 90 days postpartum, oestrus is likely to be delayed. Several studies have shown that this delay in the resumption of cyclicity occurs as a result of energy and/or protein deficiency. The availability of nutrients, particularly essential amino acids and glucose, is often potentially limiting to production in animals fed agroindustrial by-products (R. A. Leng, personal communication). These nutritional constraints combined with the reduction in voluntary feed intake that occur during thermal stress may cause a loss of body condition and lead to delayed puberty and postpartum anoestrus in the draught female.

Suckling

Oestrus and ovulation are suspended during lactation in many mammalian species including cattle and buffalo. Suckling significantly increases the interval from parturition to first oestrus in Zebu breeds and buffaloes which suckle their calves (Sharifuddin et al. 1985; Jainudeen 1984). Most draught animals have their calves 'at foot' and it is very likely that resumption of postpartum ovarian activity is delayed.

Disease

Infectious diseases contribute to long calving intervals through repeat breeding and abortion. Several reproductive diseases including brucellosis, vibriosis, trichomoniasis and infectious bovine rhinotracheitis occur in Zebu cattle and buffalo but their role, except for brucellosis, is obscure.

Future Research

The foregoing discussion has provided evidence that a tropical environment adversely affects female reproduction in cattle and buffalo. Therefore, it may be concluded that the additional stress of work imposed upon the draught female is most likely to reduce its reproductive performance. Since scientific data are lacking, more field surveys and carefully planned experiments conducted under field situations are needed to quantify the effects of draught on female reproductive performance.

Studies should be conducted to compare the reproductive performance of draught and non-draught breeding females. Length of the oestrous cycle, duration and intensity of oestrus and time of ovulation need to be established. Ovarian activity should be assessed on a combination of daily oestrus detection with a vasectomised male, rectal palpation, laparoscopic observation of ovaries and plasma progesterone assay; clinical and hormonal methods of diagnosing luteal activity are closely correlated in the cow and buffalo (Jainudeen et al. 1983). Thus, where laboratory facilities are not readily available for hormonal measurements, rectal palpation could be employed to investigate ovarian function under field conditions.

The incidence and type of anoestrus in the draught animal should be determined. Ovarian activity in the cow and buffalo can be classified into three types: a corpus luteum (CL) with detected oestrus (cycling), a CL with undetected oestrus (apparent anoestrus), and no CL with undetected oestrus (true anoestrus). Studies should be undertaken to establish the role of suckling and body condition on the resumption of postpartum ovarian activity. It may be possible to reduce the postpartum interval to first ovulation and conception in the lactating or suckled animal by increasing dietary energy intake during late gestation (Echternkamp et al. 1982), restricting suckling to once-daily from 30 days postpartum to first oestrus (Randel 1981), early weaning or calf removal for 72 hours with or without exogenous progestagen (Jainudeen 1984; Walters et al. 1984).

Under village farming systems, most draught males are castrated and the availability of sires may be limited. A decision must be made for breeding by artificial insemination or natural service. One of the primary tasks is to provide farmers intensive training in breeding management emphasising oestrus detection which is the time and labour consuming input. Alternatively, methods of oestrous synchronisation or induction could be considered because inseminations could be planned for periods when animals are not being worked. However, planned inseminations following oestrous cycle regulation have, thus far, been disappointing. Greater attention should be given to nutrition, management, clinical examination and insemination schedules in future studies.

Early Embryonic Death

Early embryonic deaths before regression of the corpus luteum are indistinguishable from failure of fertilisation in that both cow and buffalo return to oestrus at the normal time. Previous methods of determining the nature of the reproductive failure were based on the interval between insemination and return to oestrus or on milk progesterone levels. Both these methods fail to detect most of the embryonic deaths which occur before 15 days postinsemination. Studies based on recovery of ova or embryos at slaughter or nonsurgically have proved that most embryonic losses occur at a much earlier time than previously believed (see Ayalon 1984). Embryos collected nonsurgically from repeat breeder cows revealed that most embryonic abnormalities occur in the oviduct but are not apparent until about 6–7 days postservice or the blastocyst stage. Caution should be exercised in using postservice cycle lengths to estimate the time of embryonic mortality. For example, an extended cycle length may be due to reasons other than embryonic mortality. Thus a better estimate may be obtained by examining embryos which have been collected by slaughter or in vivo flushing of the reproductive tract at different days after breeding.

Reproductive Diseases

Attention should be directed toward the role of infectious diseases in the reproductive performance of the draught male. The incidence of venereal infections such as vibriosis and trichomoniasis should be established.

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A Multidisciplinary Approach to Health and Disease in Draught Ruminants

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A long list of diseases affecting ruminants can be found in veterinary textbooks, but little published information specifically relates to the health and disease of draught ruminants. Any disease which limits the productivity of ruminants will affect draught ruminants, although the relative importance of some diseases is much higher in draught animals because of the special demands made on them. Disease in animals is the end product of a multifaceted process, influenced by the nature of the causative agent, the host and the environment. This paper therefore concentrates on the dynamics of the disease process, using examples of specific diseases with particular reference to Southeast Asia. Attention is drawn to the interdependence of many disciplines in understanding the disease process, an understanding which is essential if we are to increase the work output and productivity of draught animals. The importance of sound management and husbandry practices in preventing and controlling disease is also highlighted.

Disease

Disease is a state of not (dis) being at ease (ease). Initially the disturbance may be biochemical, such as impaired liver function or increased blood ammonia or blood urea. If the disease progresses an obvious clinical lesion such as poor growth rate, lack of vigour, haemorrhage, lameness, or ulcers may be produced. Unfortunately, an animal not visibly diseased is usually assumed to be healthy, but this is often presumptuous. Sub-clinical diseases usually cause weight losses, retard growth and cause the loss of the benefits of nutritional inputs. Since weight is positively correlated to draught power output, sub-clinical disease may be far more important than overt disease, particularly in draught animals.

The three possible outcomes of a disease are death, survival with disease (chronic or sub-clinical disease), or recovery. The outcome and frequency of disease are influenced by many variables called disease determinants. These usually include one or more specific agents, as well as factors associated with the host animals and their environment. The relative importance of all identifiable determinants and the interplay between them must be considered in attempting to prevent or control diseases (Schwabe et al. 1977).

Disease Agents

Aetiological agents that affect draught animals can be divided into genetic, physical, infectious, chemical or nutritional.

Genetic Agents

Although more than 80 inherited diseases in cattle have been identified throughout the world, information on the majority of these disorders is lacking. Their relative importance in draught ruminants is probably low because congenital defects, such as enzyme deficiencies, imperfect skin formation (epitheliogenesis imperfecta) and hypospadia, for example, are rare. This is generally the case in an outbred population. Care must be taken, however, when selecting sires to prevent the spread of a genetic defect within a draught animal population. It is particularly important in government-sponsored artificial insemination schemes where the semen from one sire is used extensively. Certain genetically-caused diseases may spread insidiously through a population until they are difficult to economically control. It is highly desirable that diseases with a genetic basis be recognised early and control measures instigated.

Physical Agents

Tethering, attachment to an implement, working long hours on sometimes rough and rocky ground, pulling extremely heavy loads and competing with

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the motor car for road space predispose the draught animal to physical trauma. Diseases such as strains, tendinitis, wounds and inflamed hooves may result (Reh 1982). An examination of the mechanics of load bearing and better yoke design will help to alleviate some of these traumatic injuries as will good husbandry practices. However, not all traumatic injuries remain uncomplicated. Minor abrasion may provide a suitable site for infection with the larvae of *Chryssomia bezzaina* (the screw worm fly) which can cause extensive wounds if allowed entry through skin. In addition, trauma caused by ropes can increase susceptibility to streptothrichosis and is considered instrumental in the formation of horn cancers in Indian draught cattle (Anon 1976). It follows that daily inspection of draught animals and appropriate treatment of abrasions and wounds are desirable management procedures.

Infectious Agents

Investigation of infectious agents is an enormous field that demands and receives great attention from the veterinary profession. Major epizootic and enzootic infectious diseases caused by bacteria, viruses, helminths, protozoa, fungi, chlamydia and rickettsia need to be controlled if the full potential of the draught animal is to be realised. Foot and mouth disease and rinderpest are endemic in many countries where draught animals are an important resource. Control measures against these diseases need to be maintained and improved. Blood protozoa such as *Babesia*, and *Trypanosoma* and *Theileria* are endemic in Southeast Asia and their total economic impact is unknown. The bacterial disease, haemorrhagic septicaemia, is considered by countries in Southeast Asia to be important enough to warrant yearly vaccination to protect draught animals. Also of importance are parasitic diseases caused by round worms, flukes, and ectoparasites. These diseases are often subclinical, with production losses and reduced work output occurring unnoticed in their presence.

In a particular area, an understanding of the interplay among infectious agents and other disease determinants is a basic requirement for control of infectious diseases. The adverse effects of some infectious agents might be reduced by minor, socially-acceptable changes in management or the local environment. Others may require vaccination or regular chemical treatment, timed to achieve greatest effect with least cost and inconvenience to the owner of the animals.

Chemical Agents

Chemical agents that adversely affect draught animals may be either natural or manufactured. The most common natural chemicals available to animals are in plants or are the products of fungal infections on plants. Draught animals in some countries are fed on harvested fodder and not allowed to graze selectively. This may expose them to unpalatable and/or toxic plants presented to them. In hot humid climates feed is commonly contaminated with aflatoxins which damage the liver, resulting in a reduced immunological and metabolic competence of the host.

More use is being made of manufactured chemicals to control crop pests. This practice and the proximity of draught animals to areas of use, leads to a greater exposure to potentially harmful agents. Many of these chemicals accumulate in animal tissues, creating a potential human health problem where old draught animals are slaughtered for human consumption. Solutions to this problem are difficult; however, world opinion is turning against the use of chemicals in agriculture, thus encouraging plant breeders, research organisations and the chemical companies themselves to seek alternatives. The simple procedure of washing the animal after exposure to chemical spray may help, but control of ingested contaminants is more difficult.

Nutritional Agents

Nutrients can be either primary or secondary determinants of disease. For example, lack of calcium is the primary cause of hypocalcaemia, and lack of food the primary cause of malnutrition or starvation. However reduced calcium or food intake can also be a secondary determinant in infectious diseases which depress appetite. Nutritional deficiencies exacerbate the stresses imposed on draught animals because of the close relationship between nutritional status, the immune response and infection. Disease prevention must therefore include adequate nutrition. Nutrients will be discussed again under environmental determinants, because of the important role they play as secondary determinants of disease.

Host Determinants

Host determinants include age, species, breed, sex, genetic characteristics and immunological state.

Age

Young animals are highly susceptible to certain infectious diseases, for example, enteric infections and gastrointestinal helminths, the effects of which are often compounded in the young by poor management procedures, such as overcrowding. Innate resistance protects young animals against some diseases, such as babesiosis and anaplasmosis, which affect older susceptible animals more severely. The relative importance of venereally transmitted diseases is also age-related for obvious but entirely different reasons. Draught animals usually work hard until they are very old, predisposing them to age-related diseases such as arthritis and chronic tendinitis.

Species

Different species of domestic animals vary in their susceptibility to pathogens, although this is largely unexplored by laboratory workers. In many diseases, this difference in susceptibility is presumed to be due to the presence of inhibitory factors in some species or the absence of essential metabolites in others. A well defined example of the influence of a host metabolite is shown in *Brucella abortus* infection. Abortion occurs only in cattle and buffalo that have the rare sugar, erithritol, in their placental tissue. Buffalo are more resistant than cattle to mastitis (Wanasinghe et al. 1982), and this has important ramifications for milk production in Southeast Asia. Non-infectious disease agents may also vary in their effect on different species. For example, buffalo are much more susceptible than cattle to water deprivation (Ranawana et al. 1982).

Breed

Within a species, different susceptibilities to infection occur. For example, *Bos indicus* cattle suffer less from infectious kerato-conjunctivitis and ticks than *Bos taurus* cattle do. In addition, malignant catarrhal fever is a severe disease of Bali cattle (*Bos javanicus*) but not ongole cattle (*Bos indicus*) in Indonesia (Hoffman et al. 1984).

Sex

Some diseases are associated with only one sex, for example, parturition paresis and mastitis are related specifically to females. Brucellosis and other reproductive diseases can occur in both sexes but are potentially more important in the draught female because of the high value of her offspring as replacements. Thus the relative importance of a disease may vary with the proportion of males and females in the affected population.

Genetic Characteristics

Innate disease resistance and other genetic characteristics form the basis of animal selection, both natural and managerial, and are therefore of fundamental importance to animal health. Differences between species and breeds in their resistance to disease have been mentioned. Within-breed variability also exists, and influences considerably managerial practice in many livestock systems. The identification of individuals that are either highly resistant or highly susceptible to ticks, for use as breeders or for culling, respectively, is one example. However, genetic selection for conformational attributes which could influence disease occurrence such as correctly sloping pasterns, or strength of the claw and hoof is rarely practiced. By contrast, in some areas of Southeast Asia, in particular Indonesia, certain types of swamp buffalo are preferred, for example the black and white spotted type of Sulawesi or the albinoid type in northern Bali (Cockrill 1974), but this selection is often culturally based. In Sulawesi, the Toraja people have selected buffalo for fighting ability and strength, which has left the buffalo with a bad temper and it is rarely used for draught (Robinson 1977). In other areas where mere survival of the draught animals precludes any culling, selection on any criteria is impossible. For these reasons, breeding and selection programs to produce a superior draught animal require an enormous investment, and governments must take on this responsibility if genetically superior animals are to be produced.

Immunological State

The outcome of an infectious disease depends largely on the host's immunity, which may be specific or non-specific, natural or acquired. Even when present in the host, each type of immunity varies in its effectiveness, depending on such factors as the infecting dose, the host's nutritional status and the presence of other infectious agents. These factors may thus contribute to the variable effect of a disease outbreak in a seemingly uniform animal population.

Environmental Determinants

Environmental determinants can be broadly divided into those influenced easily by man, such as management and nutrition, and those not easily influenced by man, such as location, cultural practices, religion and socioeconomic status.

Management

The provision of adequate and good quality feed, water and shelter for animals, and their careful handling at work and at rest are obvious factors related to disease frequency. The importance of the relationship between husbandry practices and disease occurrence cannot be over-stressed. The excellent book by Williamson and Payne (1978) covers the topic in depth.

As mentioned earlier, a dramatic effect on the occurrence of some diseases can be made with very minor management changes. For example the Masai tribesmen of East Africa traditionally kept their cattle away from calving wildebeest to prevent the occurrence of malignant catarrhal fever. This was long before the causative agent was isolated and found to be secreted at calving time. In Indonesia, because of the association between sheep, cattle and malignant catarrhal fever, sheep are actively excluded from some of the outer islands. However, on the island of Java, where culturally the keeping of sheep is more important and separation from cattle difficult, other methods of control need to be investigated.

Nutrition

Unlike the drought-prone regions of the world, water is not usually a limiting nutrient in the wet tropics of Southeast Asia. However, food, the second most important factor limiting the expression of the full genetic potential of the draught animal, is in short supply in many parts of the world. Maximum performance is achieved only when a ration balanced for energy, protein, vitamins and minerals is fed to meet the animal's nutrient requirements for growth, maintenance, lactation, gestation and, in the draught animal, work output. In most places where draught animals are kept the most common deficient nutrients are energy and protein. There is a close relationship between energy and protein intake and physiological parameters of animals (Campbell 1983). A few examples are: onset of puberty, length of anoestrus, ovarian activity and activity of the host defence mechanisms. A deficiency in the essential nutrients therefore plays an important role in the expression of disease. For example, just before the monsoon season in Southeast Asia buffaloes and cattle are usually in poor condition because of a scarcity of fodder. When the rains come many of these animals must work, and this is when the incidence of haemorrhagic septicaemia rises quickly (Anon 1976). Field experience points to exhaustion, chilling and malnutrition as possible stress factors precipitating this disease.

Location

Determinants such as latitude, longitude, altitude, topography, temperature, air pressure, radiation, humidity, wind speed and direction, soil types, vegetation and fauna (especially predators and reservoirs of disease) are embodied in location. As well as affecting animals directly, these determinants can influence the quantity, quality and availability of essential nutrients, and thus modulate their nutritional status. These determinants may also interact with and/or spread infectious agents and their vectors (Johnston 1981).

Although many of the determinants mentioned cannot be easily controlled by man, their recognition allows the use of simple management procedures to minimise some of their effect. Thermal stress for example, can alter the animal's response to its dietary intake, and at the same time the food conversion ratio widens, and disease may result. Heat stress will also affect the reproductive system causing anoestrus and depressed oestrus activity. It follows that measures to reduce heat stress will have a beneficial effect.

Cultural Practices, Religion, Socioeconomics

Cultural practices, religion, socioeconomic status and personal aspirations of owners can influence the occurrence of disease. The associations between animals and man have influenced the evolution of common diseases. Over 30 diseases can be transmitted from cattle to man and some, vice versa. Interaction between draught animals and man is very high and facilitates transmission of disease, thereby contributing to zoonosis (Kakoma and Ristic 1981). Zoonoses transmitted by direct contact, such as brucellosis, staphylococcosis, tuberculosis, leptospirosis and anthrax, are important in the human/draught animal interaction. Draught animals play an integral part in the life, culture and social customs of the people who keep them. They are a source of wealth, pride, mystique and entertainment upon which no objectively determined value can be easily placed (Robinson 1977). The reason why most of the draught animals in Southeast Asia are of low genetic potential and kept at minimal cost with little attention to disease or nutrition, is complex and influenced by, among other things, socioeconomic factors. Some of these factors such as population pressure, income levels, farm size, dependence on cropping for food, lack of development capital, ownership patterns, land tenure systems and planning uncertainties need to be understood before meaningful control measures can be instigated. It is vital, in appreciating the impact of disease on draught animals, to understand the linkage between demand of draught power for crop production, the necessity for this draught power to be available at a specific time, and the socioeconomics. For example a disease outbreak during the work period can be very serious; however, the same outbreak when the animal is not required to work is of minor importance provided the animal survives (J. Copland personal communication).

Human/Draught Animal Interactions

The foregoing disease determinants are but some of the variables in and constraints on the human/draught animal interaction. Even within one country there would be many different interactions

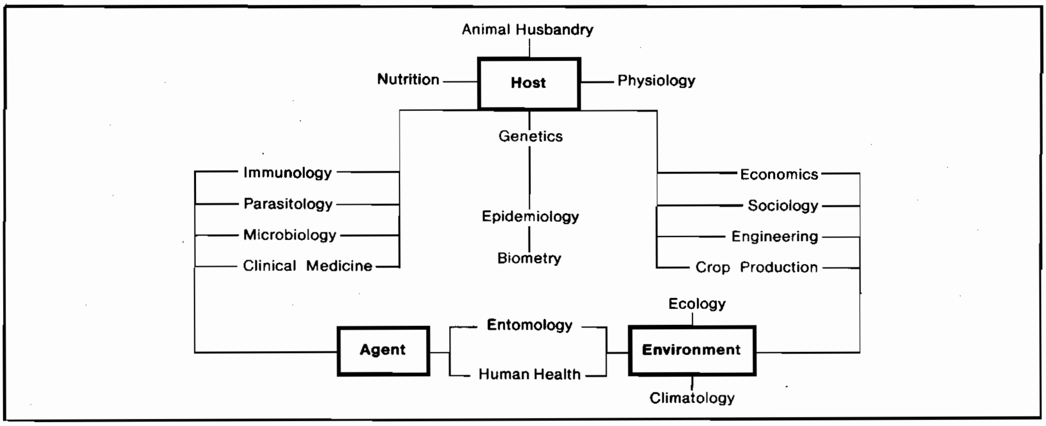

Fig. 1. Cooperative inputs and targets required for a systems approach to animal health problems.

defined by the relative importance of the determinants mentioned. To identify the relative importance of a disease and to undertake its control if warranted requires more than a study of infectious agents. There is a need for input by people with expertise in engineering, genetics, crop production, nutrition, economics, sociology, animal husbandry, human health, physiology, immunology, climatology, epidemiology, biometry, parasitology, clinical medicine, entomology and perhaps other disciplines. A systems approach is required, with consultation among all contributing groups. A single-discipline approach, which in this context can be described as 'tunnel vision', must be actively discouraged. The reasons for 'tunnel vision' include the present structures of some government departments and universities which promote division of disciplines. Competition for limited research funds adds to the tendency of special interests being projected and protected. A change in structure and attitudes within these organisations will take time and is not seen as a short-term solution to the problem. An immediate and valuable contribution towards encouraging a systems approach can, however, be made by the administrators of funding bodies and their advisers. They should require proposals for support to include a broad perspective of the human/draught animal interactions in question, and a clear intention of consultation among relevant disciplines. The appointment of coordinators to liaise between different but related projects should also be considered.

Many of the recommendations for improving our understanding of the disease process in beef cattle in developing countries which were made by Ellis and Hugh-Jones (1974) are still relevant today. Their recommendations could apply equally to the problem of increasing the productivity of draught ruminants. For example, disease problems are not yet adequately defined in draught ruminants in Southeast Asia and systematic information gathering should be given high priority. In certain countries where sufficient reliable data are not already available to aid in defining the most urgent problems, continuous observations on selected, representative interactions should be implemented (Ellis and Hugh-Jones 1974).

ACIAR, in sponsoring this workshop and bringing together experts on draught power, has made a significant contribution towards an integrated attack on the problem.

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Review of Diseases in Indonesia Affecting Draught Power in Domestic Animals

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INDONESIA is a vast archipelago spanning the equator and containing a large number of different peoples and cultures living in varied geographical locations. Oil is the most important resource, but agriculture is the most important activity and the most common livestock systems are the smallholder (11 million in 1980) and landless farmers (2 million in 1980). The most important constraints to livestock production include human overpopulation leading to land pressure (Java), climate leading to poor nutrition in dry areas (Eastern Islands), or to optimum development of certain diseases, e.g. fascioliasis in wet areas (all islands west of Lombok) and less than optimal management, disease surveillance and marketing systems in some areas.

A variety of animals are used for draught purposes in Indonesia and include swamp buffalo (*Bubalus bubalis*), ongole cattle (*Bos indicus*), Bali cattle (*Bos javanicus*) and horses. Buffalo and cattle are the most important. The predominant draught animal species varies according to area. Thus buffaloes are more commonly used in Sumatra and West Java, ongole cattle in Central and East Java, Bali cattle in Bali, South Sulawesi and Eastern Islands and cattle and horses in North Sulawesi. The most important use for draught animals is traction either for agricultural purposes in the rice paddies or for transport of goods and people. Both of these areas of traction are essential facets of the Indonesian economy.

The estimated population of buffalo, cattle and horses in Indonesia is shown in Table 1. Buffalo and cattle have shown only marginal increases over the period 1974–82 despite large imports whereas horses have shown an estimated increase of 9% over the same period. The reasons for the low increase of large ruminants is uncertain but may be due to a combination of low fertility, mortality due to disease and excessive slaughter to meet increasing demand for protein. Over the period 1978–83, a regional redistribution of large ruminant livestock occurred. The islands of Sulawesi, Sumatra and Kalimantan showed large increases. Java island showed a net loss of buffalo and a marginal increase of cattle over the same period.

Table 1. Livestock populations in Indonesia, 1974–82 (thousands).

Year	Dairy cattle	Cattle (total)	Swamp buffalo	Horses
1974	86	6380	2415	600
1975	90	6242	2432	627
1976	87	6237	2284	631
1977	91	6217	2292	659
1978	93	6330	2312	615
1979	94	6362	2432	596
1980	103	6440	2457	616
1981	113	6516	2488	637
1982	140	6594	2513	658

Source: Informasi Data Peternakan (1983). Directorate General of Livestock Services, Jakarta.

Robinson (1977), using results from a questionnaire to 597 farmers in 12 provinces, estimated that 58% of all cattle and buffalo in Indonesia are draught animals. There is a negative correlation between the number of females in herds and the percentage of draught animals in herds. In general large ruminants are kept as capital and are used as items for social exchange (e.g. bride prices), income earning (e.g. rental for draught purposes) and sources for large sums of money as required when they are sent for slaughter.

Little work has been conducted on diseases affecting draught animals and in many documents disease is barely mentioned (FAO 1972; Smith 1981; Starkey 1984). In Indonesia, Robinson (1977) recognised the importance of disease in working buffaloes and cattle, and considered haemorrhagic septicaemia to be the most important. Other dis-

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eases were mentioned, notably foot and mouth disease, surra, anthrax, scabies and piroplasmosis. Surprisingly fascioliasis (liver fluke disease) was not mentioned, although it is very common in large ruminants (Edney and Muchlis 1962). Little recent work has been conducted on diseases of horses in Indonesia, although the Dutch recognised trypanosomiasis as the most important disease of this species (Dielman 1983).

This paper will review all the main diseases known to be affecting large ruminants and horses in Indonesia, and assumes that these diseases also affect draught power. A list of these diseases according to species and divided into acute or chronic is given in Table 2 (A and B). The most important of these diseases will be briefly discussed later.

With the exception of Rukmana (1977) no detailed studies on the effect of specific diseases on draught animals have been conducted in Indonesia. Rukmana (1977) studied the effect of trypanosomiasis (surra) on draught power in buffalo and cattle. He showed that the average area of wet soil ploughed by buffalo infected with *Trypanosoma evansi* was 153 m^2/hour compared to 216 m^2/hour in normal buffalo. This resulted in an estimated economic loss of around US$45/draught animal/year (1977 values).

Acute Diseases

There are a number of acute diseases which affect large ruminants and horses in Indonesia. Some of these are species- and age-related, some cause high mortality, and others cause temporary loss of draught power followed by recovery. The overall effect of this group of diseases is a dramatic and easily visible loss of draught power. There are, therefore, endeavours to institute suitable control measures by both the government and owners. The most important diseases in this group are as follows.

Haemorrhagic Septicaemia (Cattle, Buffalo, Horses)

AETIOLOGY

In Indonesia, haemorrhogic septicaemia (HS) is the disease in cattle and buffalo caused by *Pasteurella multocida* (type 1, Roberts; type B, Carter) (Jan Nari and Sjamsudin 1973). Pasteurellosis was first reported in pigs and poultry in 1912 and in rabbits in 1926 (Utojo 1958). Deaths due to *Pasteurella* have been reported in horses (Utojo 1958).

DISTRIBUTION

From early reports, HS was recognised throughout Indonesia (Utojo 1958). The disease is still considered to be widespread and endemic throughout Indonesia in carrier animals. The organism was recently isolated from the blood of cattle slaughtered at the Bogor abattoir, although the disease in these animals was probably in the shipping fever form (Balitvet 1983a).

EPIDEMIOLOGY

There is little doubt that haemorrhagic septicaemia was the most important bacterial disease of livestock in Southeast Asia until major vaccination programs were commenced in the region (FAO 1955; Bain 1963).

In Indonesia HS is a disease with largely a seasonal distribution, the majority of deaths occurring during the rainy season. Major outbreaks with heavy mortality can occur. Physiological stress through prolonged periods of poor nutrition, and also scouring caused by the ingestion of the green shoots following the rain, are considered other predisposing factors (FAO 1955; Jan Nari and Syamsudin 1973).

Good control of HS is being achieved through annual vaccination with an oil adjuvanted strain Katha vaccine, developed and produced in Indonesia (Jan Nari and Syamsudin 1973). The disease is reported to have disappeared from the island of Lombok following a 3-year vaccination program.

Brucellosis (Cattle)

AETIOLOGY

Brucellosis of cattle in Indonesia is caused by *B. abortus* biotype 1 which has been isolated from the milk of dairy cows in East Java (Soeroso et al. 1985).

DISTRIBUTION

Brucellosis has so far remained undetected in male slaughter cattle (Balitvet 1983a) in Java but is present in ranch cattle in both North and South Sulawesi. In dairy cattle it is confined to the municipal areas of Surabaya and Jakarta and in North Sumatera (Soeroso et al. 1985). The islands of Kalimantan and Bali were found to be negative (Scott-Orr et al. 1980).

EPIDEMIOLOGY

Brucella arbortus has been detected in only 2% of dairy cows (Soeroso et al. 1985), but prevalence rates of up to 80% were found in some beef herds in North Sulawesi. Major losses in beef herds are from abortion.

Sporadic and indiscriminate use of both strain 19 and 45/20 vaccines has been made in some provinces in dairy cattle. This has complicated a test and slaughter policy which exists, although rarely implemented as there is no government compensation paid.

Table 2. Large ruminant diseases; A. Diseases known to have some significance (suggested order of economic importance).

Disease	Cause	Distribution	Significance	
Fascioliasis	Parasitic	W. end	+ + + +	o*
Trypanosomiasis	Parasitic	W. end	+ + to + + +	o*
Foot & Mouth	Viral	L. epi	+ + to + + +	o
Haemorrhagic Septicaemia	Bacterial	W. end	+ + to + + +	o
Gastrointestinal Nematodiasis	Parasitic	W. end	+ to + +	*
Ascariasis	Parasitic	W. end	+ to + +	o
Brucellosis	Bacterial	L. end; L. epi	+ to + +	o*
Stephanofilariasis (Cascado)	Parasitic	L. end	+ to + +	*
Anthrax	Bacterial	L. end; L. epi	+ to + +	o
Mastitis	Bacterial	W. end	+ + to + + +	*
Lantana poisoning	Toxicological	W. end	+ +	o
Copper deficiency	Nutritional deficiency	W. end	+ +	*
Scabies	Parasitic	W. end	+ to + +	*

Key:				
	W	widespread	+ +	moderate
	L	localised	+ + +	high
	end	endemic	+ + + +	very high
	epi	epidemic	o	acute
	+	low significance	*	chronic

B. Diseases known to occur (significance unknown)

Virological
Akabane disease
Ephemeral Fever
Ibaraki
Infectious Bovine Rhinotracheitis
Malignant Catarrhal Fever
Rabies
Bovine herpesvirus 2
Bluetongue

Bacterial
Actinobacillosis
Blackleg
Colibacillosis
Infectious bovine kerato-conjunctivitis
Leptospirosis
Salmonellosis
Tuberculosis

Mycotic
Dermatomycoses

Aetiology unknown
Jembrana disease

Parasitic
Babesiosis
Coccidiosis
Cysticerosis
Demodex
Echinococcus
Gigantocyle
Myiasis (Screw Worm)
Paramphistomes
Theileriosis

Rickettsial
Anaplasmosis
Eperythrozoonosis
Haemobartonellosis

Toxicological
Pesticide poisoning
Cyanide poisoning

Nutritionally related
Phosphorus deficiency

Horse Diseases; A. Known to have some significance.

Trypanosomiasis	Parasitic	W. end	+ + + +	o
Tetanus	Bacterial	L. epi	+ to + +	o

B. Known to occur (significance unknown).

Anthrax
Melioidosis
Babesiosis
Histoplasmosis
Rabies
Strongylosis

Anthrax (Cattle, Buffalo, Horses)

AETIOLOGY

Anthrax is a peracute or acute disease caused by *Bacillus anthracis*. In Indonesia the disease has been reported to commonly affect cattle and buffalo and less commonly horses (Soemanagara 1958).

DISTRIBUTION

Although anthrax is endemic throughout Indonesia outbreaks are sporadic, occurring most commonly in Nusa Tenggara province but also in other areas (Soemanagara 1958).

EPIDEMIOLOGY

Historically, anthrax in Indonesia has been recognised and control programs in endemic areas through vaccination have kept the disease to minimal proportions. Recent outbreaks diagnosed at Balitvet have all been associated with human deaths indicating the importance of anthrax as a zoonotic disease.

Foot and Mouth Disease (Cattle and Buffalo)

AETIOLOGY

FMD has been reported for many years in cattle and buffalo in Indonesia with outbreaks occurring at regular intervals, although no outbreaks were reported during the period 1980–83. Only type 'O' virus has been identified. In a recent outbreak in Java in 1983, the causal virus was identified as similar to 'Ol Campos' by the FMD World Reference Centre.

DISTRIBUTION

FMD is currently thought to occur only on the island of Java, although in previous years, it has been reported from other islands.

EPIDEMIOLOGY

The Indonesian FMD virus is thought to occur mainly in large ruminants, and these animals only are vaccinated. The virus can cause severe clinical disease. A number of 'O' vaccines from various sources are used in Indonesia and these have been evaluated (Ronohardjo 1984). Control relies on biennial vaccination of all large ruminants on Java island.

Malignant Catarrhal Fever (Cattle and Buffalo)

AETIOLOGY

Two forms of disease are recognised, namely, wildebeest associated (WAMCF) caused by a herpes virus and sheep associated (SAMCF) of unknown aetiology.

DISTRIBUTION

Only SAMCF has been reported in Indonesia in Bali cattle (Ginting 1979), buffalo (Hoffman et al. 1984) and deer. The disease occurs throughout the country.

EPIDEMIOLOGY

SAMCF occurs mainly in Bali cattle and in buffalo where characteristically the disease is sporadic, acute to subacute and with a very high mortality. Infrequently, the disease occurs in *Bos indicus* and *Bos taurus* cattle.

Jembrana Disease (Bali Cattle)

AETIOLOGY

Jembrana disease is an acute disease of unknown aetiology affecting mainly Bali cattle.

DISTRIBUTION

The island of Bali with a possible location in South Sumatra.

EPIDEMIOLOGY

Many aspects of the epidemiology of the disease require clarification. In general, outbreaks are sporadic involving both large and small numbers. The disease is now thought to be endemic in Bali with a mortality rate of 13% in untreated cases (Budiarso and Hardjosworo 1977).

Anaplasmosis (Cattle and Buffalo)

AETIOLOGY

Anaplasmosis is an acute disease of large ruminants caused by the rickettsial blood parasites *Anaplasma marginale* and the less pathogenic *A. centrale* and transmitted by *Boophilus* ticks.

DISTRIBUTION

The disease occurs throughout Indonesia as *B. microplus* is found on all islands.

EPIDEMIOLOGY

There is an age resistance in calves leading to areas of disease stability in enzootic areas. However, high mortality can occur in imported, naive adult animals.

Chronic Diseases

There are also a number of chronic diseases affecting large ruminants and horses in Indonesia. These include trypanosomiasis (surra) which is the most important disease of horses. The effects of this group of diseases are not dramatic and in many instances pass unnoticed. However, their overall economic effects may be greater than the group of acute diseases as their incidence is much higher and they cause long-term effects on fertility, growth rate and therefore work capacity. General control measures are rarely undertaken against any in the group of diseases of which the most important are as follows:

Fascioliasis—Liver Fluke Disease (Buffalo, Cattle)

AETIOLOGY

Two species of fluke can be found in the livers or large ruminants in Indonesia, namely *Fasciola gigantica* and *Gigantocotyle explanatum*. There are reports of *F. hepatica* (Rivai 1979) occurring in the country but these need to be confirmed.

DISTRIBUTION

Surveys in abattoirs have been conducted in many parts of Indonesia and show that fascioliasis is both common and widespread, probably occurring on all the main islands. Prevalence rates as high as 90% have been reported in some areas (Edney and Muchlis 1962). *Gigantocotyle explanatum* was found in 7% of cattle and buffalo examined at the Bogor abattoir (Henderson 1979).

EPIDEMIOLOGY

The snail intermediate host is likely to be found in wet areas on all islands. Animals of any age can be infected with liver flukes with increased resistance with age occurring in large ruminants.

Fascioliasis can cause both acute (more common in small ruminants) and chronic disease. The latter is the most common type in large ruminants causing severe weight loss and condemnation of livers at abattoirs. The pathological effects of *G. explanatum* have not been studied in detail.

There is little control of liver fluke disease in Indonesia due to expense of chemotherapy and lack of drug distribution.

Trypanosomiasis—Surra (Horses, Buffalo, Cattle)

AETIOLOGY

Surra in Indonesia is caused by *Trypanosoma brucei evansi* and is found in horses, cattle, buffalo and dogs.

DISTRIBUTION

The parasite is thought to occur in all the main islands of Indonesia with the exception of Irian Jaya (Adiwinata and Dachlan 1972). Few definitive studies have been conducted.

EPIDEMIOLOGY

Trypanosoma evansi is spread mechanically by biting insects and at least 26 species can harbour the parasite in their mouthparts (Nieschultz 1930). Buffalo are more commonly infected than cattle (Wilson et al. 1983; Partoutomo et al. 1984) both on serology and on detection of circulating parasites. Using the ELISA test, around 60% of buffalo in sentinel herds in Java were serologically positive compared to 35% of cattle (Luckins 1983).

Trypanosomiasis can be acute (mainly in horses) or chronic (mainly in large ruminants) with anaemia and loss of weight being the main symptoms (Partoutomo et al. 1984).

Control varies from province to province where the trypanocides Suramin (Naganol) and the Isomethamidium (Trypamidium) are used.

Gastrointestinal Nematodiasis (Cattle, Buffalo)

AETIOLOGY

GIN is caused by a number of nematodes including *Haemonchus contortus* and *Trichostrongylus* sp. in the abomasum, is a disease of most importance in small ruminants; however, large ruminants are also commonly affected.

DISTRIBUTION

These parasites are widespread in Indonesia and are found in all islands. Most surveys indicate that 60–90% of both young and adult small ruminants harbour *H. contortus*. The percentage of cattle and buffalo infected with *Haemonchus* is much lower (Balitvet 1983).

EPIDEMIOLOGY

A direct life cycle occurs and most areas of Indonesia have optimal weather conditions for rapid larval development on the pasture. Both acute and chronic forms of the disease occur with death and poor weight gains respectively being the main symptoms.

Anthelmintics are not widely used in the field although recent trials have shown that improved weight gain can result from suitable drug treatment (Henderson 1979; Stevenson et al. 1983). The latter study indicated that high cost-benefit ratios could result.

Stephanofilariasis—Cascado (Cattle)

AETIOLOGY

At least two species of *Stephanofilaria* occur in Indonesia, namely *S. kaeli* which mainly affects the legs of cattle and has been reported in West Sumatera (Partoutomo 1979) and *S. dedosi* which generally causes lesions around the eyes, neck, withers, shoulders and dewlap of cattle. The latter species is the main cause of cascado.

DISTRIBUTION

Stephanofilaria infection is widespread in the country but only in certain areas, such as Sulawesi, Kalimantan and parts of Sumatera, are large lesions of cascado frequently seen. Infection rates of up to 90% have been reported (Muchlis and Partoutomo, unpublished data).

EPIDEMIOLOGY

The parasite can be transmitted by different species of biting flies, however the role of specific vectors requires clarification. Infection with *S. dedosi* results in loss of draught power in affected animals. There is also reduction in the value of hides.

Control of the infection is difficult. Neguvon (Trichlorfon) has been tested in buffaloes and cattle infected with stephanofilariasis but prolonged treatment is required (Fadzil 1977). Recently Ivermectin has been tested in Indonesia with some success (Balitvet 1984).

Sarcoptic Mange (Buffalo)

AETIOLOGY

Sarcoptes scabei is an important parasite of buffalo.

DISTRIBUTION

It is widespread in Indonesia.

EPIDEMIOLOGY

The mite causes a severe dermatitis and is found in buffalo but not in cattle and horses in Indonesia (Sangvaranond 1979). The incidence of the disease in buffaloes increases during the dry season (Griffiths 1974). Economic loss has not been assessed and there is little information on comparative treatment regimes. Recently Ivermectin has shown good results (Balitvet 1984b).

Discussion

The importance of draught power may be decreasing due to increased mechanisation and the large increase of landless farmers. Nevertheless draught power remains the most important form of traction in Indonesia and is likely to remain so for many years to come.

A large number of diseases affect draught animals and their combined effects are likely to have a significant economic effect on the efficiency of draught animal power throughout Indonesia. This effect is probably most serious for smallholder farmers where draught power is necessary to survival.

Studies on the effects of disease on draught power is a neglected area mainly due to the difficulties in developing accurate methods of study. However the importance of conducting such studies is well recognised and it is to be hoped that efforts will be made to overcome problems in experimental methodology. It is recommended that disease studies should not be undertaken in isolation but be combined with studies on nutrition, management and socioeconomics. The establishment of draught animal research units in relevant institutes in countries where draught power is important would seem a logical outcome to successful research programs.

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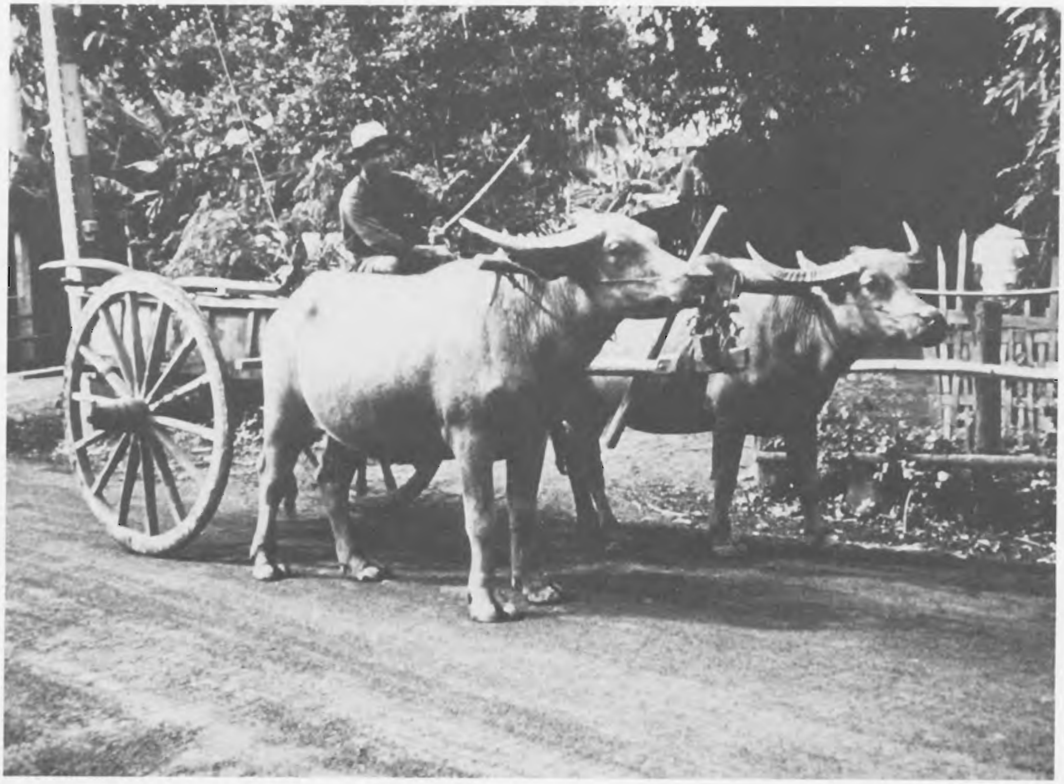

Engineering Systems for Draught Power

Engineering Problems in the Measurement of Draught Animal Performance

R. H. Macmillan*

PHYSICAL work by humans and animals is a complex interactive process involving both the active and passive elements in a power transmission and control system. It is highly variable, both in time and place, and is subject to many constraints of a physical, physiological and behavioural kind (Brody 1945).

The relationships for an animal-implement-human system are illustrated in Fig. 1. The thick lines represent mainly active and reactive forces in the power transmission process; the thin lines represent mainly control processes.

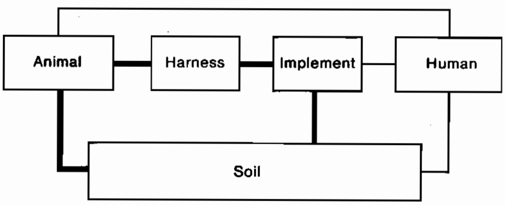

Fig. 1. Block diagram showing power transmission and control processes for working animal and implement with human operator.

The study of the engineering aspects of the animal draught processes has, to a large extent, been neglected in favour of the more recent, but inherently more simple, mechanistic system based on the agricultural tractor.

Animal-Implement Characteristics

General

Draught animals doing agricultural work constitute a prime mover-implement system, the characteristic of which is determined by the individual characteristics of its two components. At a most fundamental level, these are represented by: the speed-draught characteristic of the implement, and the draught-speed characteristic of the prime mover.

These two characteristics are essentially independent of each other because they have different origins and are limited by different constraints. They only become related when the prime mover is connected to the implement, as shown in Fig. 2. Then:

implement speed = prime mover speed
prime mover draught = implement draught.

It follows then that for a full exploration of the characteristics of the prime mover and of the implement, they should be evaluated separately. This applies to prime movers and to implements in general.

The important qualification which is necessary when the prime mover is an animal is that its output is not mechanistically determined as it is for an engine or tractor. It will vary in the short term (< 1 day) due to tiredness, hunger, and, in the long-term, ageing.

In both time frames, it will also vary with nutrition, season, weather and the reproductive stage of the animal. These external variables would have to be controlled or accounted for if meaningful long-term comparisons are to be made.

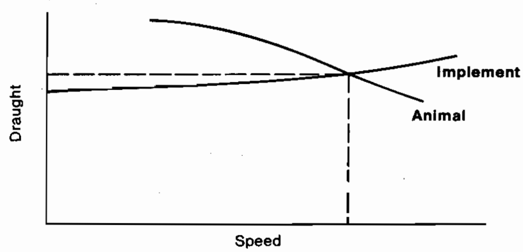

Fig. 2. Prime mover and implement draught-speed characteristics.

Animal Characteristics

The animal is a prime mover in draught work and the question arises as to what parameters should be used to specify its performance. In seeking an answer to this question, it is assumed that we wish to study those aspects of the animal, etc., which can be varied in some way to maximise the perform-

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ance. Such aspects will include breeding, nutrition, environment, management and harness/implement.

We must therefore use measures of performance which will reveal maximum benefit to the user, but be sensitive to changes in these aspects. One such measure is the maximum power which can be sustained for various periods of time within the daily working period.

As discussed in other papers in these Proceedings, the work of draught animals is based on the physiological processes associated with movement and muscular activity. Draught work will therefore be subject to the constraints inherent in these processes, as well as size, nutrition and behavioural factors.

The first constraint arises from the hydrolysis of a more or less finite store of compounds available within the muscle (Astrand and Rodahl 1970). These are able to produce a corresponding but finite quantity of energy before replacement is necessary. The power which may be developed from a fixed quantity of energy will vary inversely with the time period over which it is sustained. Results which are in accordance with this inverse relationship are obtained from humans (Fig. 3 from Wilkie 1960) and could be expected from draught animals.

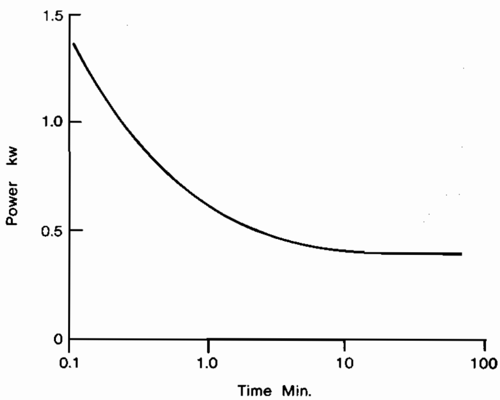

Fig. 3. Maximum power-maximum time characteristics for humans (after Wilkie 1960).

The second constraint is from the oxidation of compounds by oxygen absorbed at the lungs and transported by the blood stream. Since both of these organs have a limited capacity, this results in a more or less finite maximum rate of energy production. This in turn results in a constant power being developed for periods greater than the constant energy phase, but less than the limit set by long-term fatigue and hunger. If these concepts apply to the working animal, the question arises as to what are the implications of this for the objective testing of its performance.

In relation to field work, the long-term constant power phase of the animal characteristic is likely to be more important than the short-term constant energy phase. It follows then that any given power output is not of itself sufficient to specify animal performance for comparative purposes. Rather, if a power level is chosen, it is not this level which defines the capacity of the animal, but the time for which it can be sustained.

The difficulty here is that this time is not a clearly defined value because it is based on the willingness and the capacity of the animal to keep operating at that particular power level until it is exhausted.

In the human animal, the maximum time for which an activity can be sustained is psychologically as well as physiologically determined. In the long-distance athlete, this is his will to win. For the draught animal, presumably no such will exists; rather, it is likely to be a will to stop and hence the animal is unlikely of itself to reach this exhaustion limit.

What is required is an objective physiological measure of the extent of tiredness, exhaustion or energy depletion which would be more sensitive to treatments such as nutrition than would time to exhaustion.

Implement Characteristics

As indicated above, the performance characteristics of animals and implements ought to be determined separately. However, the types of work which animals perform vary widely, as do the characteristics of that work in terms of draught and speed. The question arises, therefore, as to what draught-speed characteristic we should seek to simulate. In answering this, it is probably reasonable to assume that the tillage operations constitute the heaviest and most common activity for draught animals; this should therefore be made the basis for testing them and an attempt made to simulate this process.

The typical mean draught-speed characteristic for tillage implements is as shown in Fig. 2. This suggests that there is a minimum draught which must be overcome before any motion is achieved and then, depending on the implement, the draught force increases slightly as the speed is increased.

Energy Absorption Systems

General

As noted above, the output of a prime mover may be specified in terms of draught and linear travel speed. When converted to rotary motion, these correspond to torque and rotational speed.

The draught animal, though not a machine, is a prime mover, hence its instantaneous performance may be expressed in the above terms. However, this performance is subject to physiological and behavioural constraints and is dependent on the long-term as well as the short-term history to which the animal has been subjected.

The use of a field implement as a load for an animal does not provide an adequate range in the draught force, nor does it provide control of this force. It reveals more about the implement than it does about the animal.

In studying the animal, it is therefore important to develop a system of loading it which will: (a) simulate the conditions and the draught force arising from the common agricultural operations; (b) allow this draught force to be varied to fully explore the animal's performance and held constant so that the effect of other aspects can be studied; and (c) allow the main performance parameters to be measured and recorded.

The question arises as to what energy-absorbing system will best simulate the typical field loading and what mechanical arrangement would be most suitable with which to operate the animal.

Terminology

A system to absorb and measure mechanical energy is known generally in engineering as a 'dynamometer'. It is probably best if its use is restricted to this meaning and it will be so used in this review. The word dynamometer is often also used to describe a 'force-meter' or 'load-cell'. While this use of the word is not inconsistent with its etymological origin, it is somewhat confusing, given its other meaning, and should be avoided.

The word 'ergometer' (literally, work measurer) should be restricted to a combined load cell and distance measuring system which has a read-out representing energy developed or work done.

High-Speed Devices

Most conventional engineering prime movers such as engines are high-speed rotational devices, hence the dynamometers, which are used to measure their performance, have similar high-speed characteristics (Fig. 4). They are usually based on torque measurement of a stationary reaction on the chassis of a device such as an electric generator or centrifugal-type pump or fan. Speed is measured using a tachometer or revolution counter and stopwatch.

Animal operation is, however, characterised by low travel speed and when this is converted to rotary motion, it produces low rotational speed, as shown

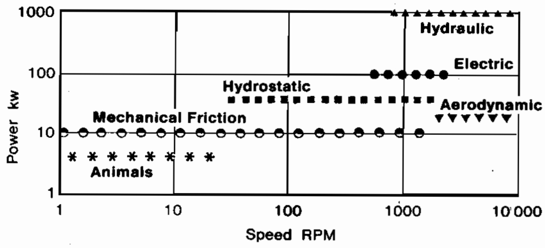

Fig. 4. Typical maximum power and speed range for conventional dynamometers and animal teams.

in Fig. 4. Conventional dynamometers are therefore not suitable for use with animals, unless a speed-increasing device (with a ratio of 1:200 or more) is included between the animal and the dynamometer.

Such an arrangement would be relatively expensive and would lose a significant proportion of the power being transmitted. This would result in the inability to apply small loads and in poor load control. High speed energy absorption/measurement devices are therefore not likely to be suitable for an application to the measurement of animal performance and will not be considered further.

Low-Speed Devices

MECHANICAL FRICTION

The simplest low-speed process is mechanical or so-called 'dry' friction. This has a force-speed characteristic, as shown in Fig. 5, which corresponds approximately with the characteristic which we are seeking to simulate, as shown in Fig. 2 above. Such a process can be achieved most easily with a mechanical brake; the disc type, with good heat dissipation characteristics, is likely to be best.

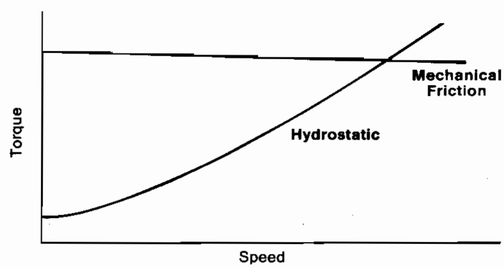

Fig. 5. Torque-speed characteristics of mechanical friction and hydrostatic systems.

The main advantages of such a system, if incorporated into an animal dynamometer, would be that it is simple and that it would have a definite draught at zero speed. It would have also a near constant draught-speed characteristic at the very low speeds and the powers likely to be encountered in animal draught work. If a speed-increasing gear box were required, this would be limited to a ratio of about 1:10. The disc brake would also provide a constant but readily adjustable load without pulsations, although these could be provided if required. This may cause the animal to balk, although it could simulate, to some extent, the load fluctuations which occur with an actual implement.

Adjustment of the draught would be provided by varying the air pressure in the actuating mechanism of the brake caliper. The input torque corresponding to the draught force would be measured by measuring the equal and opposite reaction torque acting on the caliper.

HYDROSTATIC

The hydrostatic system would consist of a positive displacement pump, pumping fluid around a circuit which would include a throttle valve to provide a resistance against which the pump would operate. It may also need a cooler to limit the temperature rise in the fluid.

The main characteristic of such a device would be the variable delivery as the piston (or the equivalent) passes through its suction and delivery strokes. This will produce a low, then high, torque respectively. In order to reduce this effect, a multi-cylinder pump would be required and also an air vessel to act as an accumulator to reduce the pressure fluctuations.

It would, of course, be possible to increase the pump speed with speed-increasing gearing and also use of a pressure-compensating valve in the circuit to cyclically open and close the throttle valve to keep the delivery pressure constant. Any pulsation in pressure in the fluid circuit as the piston passed through its delivery stroke would again be seen by the animal as a fluctuation in the draught.

For a hydrostatic system where flow through an orifice is the controlling process, the pressure ($\equiv$ draught force) will be approximately zero when the flow ($\equiv$ speed) is zero, as shown in Fig. 5. The animals would therefore feel a reducing draught as they slowed down and stopped. This may be satisfactory from an operational viewpoint, but it does not simulate the characteristic of an implement which will be essentially constant as speed falls to zero, as shown in Fig. 2.

Dynamometer Mechanisms

The above review considers briefly the characteristics of the energy-absorbing processes which might be used in a dynamometer to absorb energy from a draught animal. It leaves open the question of the form which the mechanism or measurement system might take; these are summarised in Table 1 and discussed below.

Load Vehicle

The load vehicle dynamometer would consist of a draught machine pulled by the animal and using a ground drive from the wheels to drive an energy-absorbing mechanism such as a brake or pump, as discussed above. The vehicle would have to be heavy enough to avoid excessive negative slip of the wheels, but weights could be added or removed according to the magnitude of the draught being measured.

Versatility would be a feature of such a vehicle because it could be operated on most surfaces. However, some problems may be encountered if the surface is a puddled soil and/or the minimum load (corresponding to the rolling resistance of the vehicle) is too high. Alternatively, a rough surface would create vibrations in the measuring system which, while realistic, could introduce extraneous forces and make data gathering more difficult.

An arrangement which would overcome these problems would be to have a firm smooth path for the vehicle and alternative surface conditions on which the animal(s) could operate. This would detract somewhat from the versatility of the concept. The unit would be easily transported to any location, but could be operated indoors if a large area was available.

The draught force would be measured either directly as the force applied by the animal to the vehicle or, alternatively, as the reaction on the body of an energy-absorbing device such as a hydrostatic pump or friction brake. If the latter, the rolling resistance of the vehicle would constitute an unmeasured loss.

Table 1. Characteristics of different dynamometer systems.

Type	Load	Speed control	Surface	Location
Vehicle	Draught	No	Any	Mobile
Whim	Draught	No	Controlled	Portable
Treadmill				
—active	Draught	Yes	Artificial	Portable
—passive	Physiological	No	Artificial	Portable

Whim

A dynamometer of this type would be based on the concept of the traditional whim (or 'horse-works'), whereby the animal is constrained to move on a circular path and drive an energy-absorbing mechanism by means of a torque arm. Such a system would also simulate the working environment, including different surfaces, and could, if required, be moved to allow work in different areas.

The length of the torque arm necessary to obtain a satisfactory circular path results in very large torques being required at the absorption device to oppose the motion of the animal. The arm would rotate at speeds of 2–4 rev/min.

A single or double disc brake could be used to absorb the energy, but the use of a hydrostatic pump alone is unlikely to be effective at such low speed and a speed-increasing drive would be required. If such a drive were used with the pump (or the friction brake), it would be necessary to take into account the energy losses in it. Alternatively, it would be possible to measure the draught force directly between the animal and the torque arm. However, this force is rotating and the signal from it would have to be transmitted to the stationary recording instruments via special signal processing equipment and slip rings.

Treadmill

Two types of treadmill are possible, both consisting of a belt on which the animal walks.

PASSIVE

In the passive type, the belt is on a slope Θ and is driven rearwards and downwards under the action of the component of the animal weight down the slope ($W \sin \Theta$). As the belt moves, the animal walks forward relative to the belt, but remains stationary in space. Such a system was the basis for the traditional animal- or human-driven treadmill. If used to measure animal draught performance, the pulley driven by the belt would in turn drive a brake (as described above) which would absorb the energy.

As the animal walks, positive external work is done corresponding to the component of the animal weight down the slope and the distance moved. The animal senses no actual draught load on its body, but is continuously walking uphill and lifting its own weight. Such a system would be suitable for generating various physiological loads as a basis for other experimentation. However, it would not be suitable for testing physical equipment such as harness.

The mechanical construction detail will be important because the friction load in the belt and roller mechanism will determine the minimum load to which the animal can be subjected.

ACTIVE

In the active type of treadmill, the belt is driven rearwards by an external drive while the animal walks forward to maintain its position on the belt (Brody 1945; Lawrence and Mathers, personal communication).

If the belt is horizontal and the animal walks freely, it is subject to a certain physiological load, equivalent to that of normal walking. This represents the 'zero' load condition, since no external work is done; the physiological load will be greater if a weight is carried. If a horizontal load is applied to the animal through a harness, extra energy will be generated due to the external work which will be done in resisting the draught as the belt is moved past the animal.

If, alternatively, the belt is inclined at an angle, the component of the animal weight down the slope corresponds to the force and external work is done by the animal in moving up the slope. If both an inclined belt and an external load (parallel to the slope) are included, there will be two components of external work, viz. that due to the weight down the slope and the external load.

The advantages of the treadmill are that the animal is stationary, hence the environment around it can be easily controlled and its physiological and other performance data readily measured. It involves the animal walking on and working in a strange environment and walking on an artificial surface, but these factors can be compensated for, to some extent, by training (Lawrence and Mathers, personal communication).

Both types of treadmill are suitable for generating a physiological load, but the ability to have an animal working in harness would seem to be an important reason which favours general adoption of the active type, if a treadmill system is desired.

Data Acquisition

Introduction

The effectiveness and efficiency of research on draught animal performance is likely to depend on the availability of suitable research equipment (as described above, or the equivalent), but also on the instrumentation and data acquisition facilities provided.

Conventional electronic equipment is ideal for multichannel data generation and display and, although expensive, is likely to be a worthwhile investment in the long term. The use of microprocessors as the basis for the data storage and calculation provides a significant advantage over manually read systems. The following processes are involved: generation—transducers; processing—amplification, analogue to digital conversion, integration; display—time-averaged, cumulative; calculation; recording—printing, plotting.

The parameters which are likely to be important in monitoring the output performance of an animal are as shown:

Variable	Signal Form	Short Term	Long Term
elapsed time	digital	—	recording
distance travelled	digital	—	recording
speed	digital	monitoring	recording
draught force	analogue to digital	monitoring	recording
energy	digital	—	recording
power	digital	monitoring	—

A functional circuit diagram for the parameters representing the output performance is shown in Fig. 6. The physiological parameters which would also have to be measured are not shown, but could be included as part of the complete data acquisition system.

Two types of display are envisaged. Draught force, speed and power would be integrated over short periods (5–10 sec) and displayed with that frequency for monitoring purposes. Draught force would be integrated and elapsed time, distance travelled, and work done, would be cumulated over the full period of any test.

Output Performance Parameters

ELAPSED TIME

This would be generated by an inbuilt clock and would be the basis for determination of speed and power, and for the time-averaged values of these and of draught force.

DISTANCE TRAVELLED

Distance travelled is required for both determination of speed, power and energy. It may be most conveniently measured by a rotating pulse generator or encoder, which produces a fixed number of pulses per revolution. This would be driven from a rotating member such as the torque arm on the whim or the main pulley for the treadmill; from this record, the distance travelled would be determined directly.

For a vehicle-type dynamometer, a free-rolling wheel should be used. It is then necessary to calibrate this wheel on the surface being used, because the relationship between distance travelled and number of revolutions is a function of the rolling characteristics of the wheel and the surface (Makin and Reid 1984). A counter would give a cumulative total of the pulses from which the distance travelled in the complete test could be calculated.

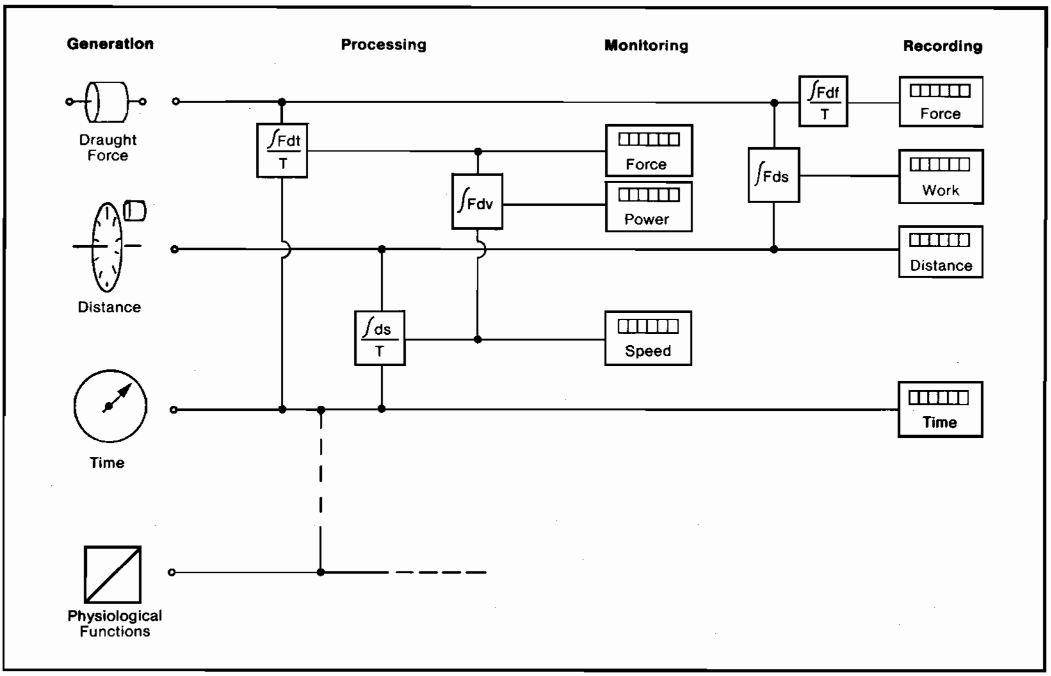

Fig. 6. Functional circuit diagram for data acquisition system.

SPEED

Speed is a parameter which would be useful for monitoring the progress of the test. The mean values would be calculated over short monitoring periods from the elapsed time and distance data and displayed for monitoring purposes.

ANIMAL DRAUGHT FORCE

Draught force is the major performance parameter. It may be measured with an electronic load cell, which would give an analogue signal. This would then be amplified and converted to a digital form for processing.

For the purposes of setting the energy-absorbing device on the dynamometer (hence the draught) and for monitoring it during the progress of the test, a time-averaged value of draught force is required, calculated over the short monitoring periods. A time-averaged value taken over the period of the test may also be of value as a record and would be provided from the data as taken.

WORK

The work done by the animal is the one single value which probably best represents the magnitude of the test. It is derived from an integration of the instantaneous force values and the equal increments of distance as determined by the distance encoder. The data handling system would give a cumulative total of the work done during the complete test.

The error in using a time-averaged force (taken over short time periods) for calculation of work done has been illustrated by Lawrence and Pearson (personal communication and 1985).

POWER

Power developed is a further useful parameter for monitoring the progress of a test. It would be calculated from the instantaneous values of force, distance and time integrated over the short monitoring period.

Conclusions and Recommendations

Effective and efficient research on draught animal performance would be greatly helped by the use of facilities for the controlled loading of the animal and the measurement of its output and physiological performance. Such equipment is specialised because the animal operates at a very low speed. The use of a speed-increasing transmission and the choice of the energy-absorbing mechanism need to be considered, together with the form of the dynamometer.

The maximum capacity of the equipment needs to be considered according to the size and number of animals to be tested at any one time. Instrumentation and data handling systems have the capability of providing a complete data acquisition service, together with improved accuracy and reduced labour. They should be chosen, however, according to the needs of the local situation and the capability to maintain them.

The careful design of both the mechanical and electrical components, and the development of at least one prototype and one final version of the dynamometer system, would enable various institutions to obtain proven designs for local adaptation and use.

Acknowledgements

Discussions with Drs Smith, Pearson and Lawrence of the Centre for Tropical Veterinary Medicine, Scotland, and with Mr G. Parkhill of the University of Melbourne, are gratefully acknowledged.

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Engineering and Draught Animal Power

B. S. Pathak*

THE combination of draught animals and relatively simple implements has been the mainstay of production agriculture in a large number of countries. With limited requirements for food and adequate land resource for maintaining animals, the output of the draught animal-implement system was not critical in the past. The situation has drastically changed, however, since the Second World War. Maximisation of the system output without overstraining the draught animals is a practical need of many countries in the developing world in order to maintain and raise the production capacity of agriculture. Alleviating some of the system limitations which act as constraints to the introduction of new production techniques is equally important under most situations. The twin objectives of enhanced draught animal-implement system capacity and making it compatible with modern techniques of agricultural production are being pursued through better understanding of the work capacity of draught animals and through improvement of implements, harnesses and system management. This paper discusses some engineering aspects related to the capacity and performance of draught animal power-implement system. Although oxen have been taken as the power unit, the principles would apply to other draught animals.

Draught Power Mechanics

A draught animal supplies useful power by exerting pull at a certain speed. The power required to achieve its own locomotion, which could be substantial under certain conditions, is neglected, although in exceptional cases like trampling of wet soils by animals to prepare a puddled seed bed for rice, self-locomotion is the only useful work done by the animal. The magnitude of pull exerted by the animal depends on the load (resistance to movement) and the method of attaching the animal or animals to the load.

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The maximum pulling capacity of an animal is decided by many factors, e.g. species, breed, sex, size, age, health, nutrition, training, work posture, ground conditions and a wide range of variables which together determine its working conditions. In general the line of pull (resistance) is not horizontal and the pull has a horizontal and vertical component (Fig. 1). The vertical component is not considered useful, although a limited vertical force might be necessary to accomplish the task. This is discussed later. The horizontal component of pull is termed as draught.

A simplified model of the forces acting on a draught animal exerting a pull has been developed by Devnani (1982). Figure 1 gives the free body diagram of bullock exerting a pull P through a neck yoke.

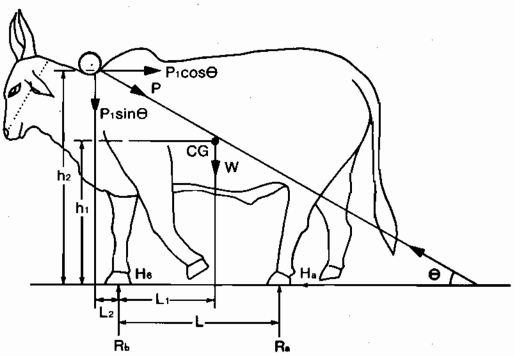

Fig. 1. Forces acting on an ox exerting pull through neck yoke.

The forces acting on the bullock, as indicated in Fig. 1, are:

- W = Weight of the animal acting at the CG.
- Ra = Vertical reaction at the rear foot.
- Rb = Vertical reaction at the front foot.
- Ha = Horizontal reaction at the rear foot.
- Hb = Horizontal reaction at the front foot.
- P = Pull.
- Θ = Angle of line of pull from horizontal.
- L = Horizontal distance between front and rear feet.
- L_1 = Horizontal distance between front foot and

centre of gravity (CG) of the animal.

L_2 = Horizontal distance of the neck load point from the front foot.

h_1 = Height of CG from ground.

h_2 = Height of neck load point from the ground.

μ = Coefficient of friction between hoof and ground surface.

Devnani made certain assumptions to develop an equation for the determination of pull under conditions of equilibrium of forces. The bullock was assumed to move on a hard plane surface at uniform speed, inertia forces were ignored, the position of CG was assumed to remain unchanged during motion and the tractive effort was assumed to be developed only by the rear feet. By writing the equilibrium equations and through a series of simple mathematical steps, the following equation is arrived at:

$$P = \frac{W.L_1.\mu}{(L-h_2.\mu)\ \text{Cos}\ \Theta + L_2.\mu.\ \text{Sin}\ \Theta}$$

The above equation is further simplified if the line of pull approaches a horizontal direction with value cos Θ approaching one and the value of sin Θ approaching zero. Under such conditions the equation can be rewritten as follows:

$$\text{Draught} = P \frac{W.L_1.\mu}{L-h_2.\mu}$$

Under static conditions the values of L and L_1 are constant and the maximum pull exerted by an ox is determined by its body weight and the coefficient of friction between hoof and the ground. Under most conditions the hooves do not slip and most likely the physiological limit for exerting pull is reached before friction between the hooves and ground becomes a limiting factor. The maximum pull or draught developed by an animal is often correlated with body weight. Swami Rao (1964) reported that the draught developed by bullocks varied from 14.5 to 24.5% of the body weight. The draught capacity of bullocks on level hard surface was reported to vary from 13 to 16% of body weight by Premi (1979). Based on field observations, I feel that the draught capacity in a full day operation may not exceed 10–12% of body weight.

The analysis carried out by Devnani (1982) is a good example of application of mechanics for the determination of draught capacity. But in its present form the analysis suffers from many limitations. The value of P determined by the equations given earlier represents the pull that can be exerted under static conditions. It does not provide for differences in breed, health, age, etc. All forces, dimensions, and location of CG are assumed to be constant. With the exception of W and L all other values fluctuate and change under actual working conditions. Deformation of soil under the hoof, fluctuations in load (the peak draught during ploughing may be two to three times the average draught), inertia forces, the tendency of the animal to change its posture during work to adjust to the changes in different forces are some of the additional factors which need to be taken into account. The dynamics of draught power generation are complex. Much more effort will have to go into its modelling before results of practical value become available.

Draught Power and Energy

While more attention is paid to the draught or pulling capacity of an animal, speed of the animal is an equally important determinant of the power output of an animal. The power outputs of a horse, an ox and a buffalo producing the same draught are likely to have a ratio of 1:0.7:0.5 because of the difference in the speeds of the three animals. Draught power is therefore a more complete measurement of the performance of draught animals. The speed of a draught animal is easy to measure. However, it has to be measured at frequent intervals throughout the duration of the task because it does not remain constant. Acharya et al. (1979) reported a considerable reduction in the speed of oxen as the task progressed (Table 1). The studies made by Rautray and Srivastava (1982) confirmed that the speed and power output of a heavy pair of crossbred oxen reduced with time and that the rate of reduction depended on the draught. Only Maurya (1982) has reported constant power output implying constant speed throughout the duration of the task. During the recent testing of agricultural implements at the Agricultural Implements Research and Improvement Centre at Melkassa (Ethiopia) measurable reduction in the speed of a pair of bullocks was noticed on a hot working day within 30 minutes of starting of ploughing with a soil-turning implement. In my opinion speed of the animals should be measured at least every hour in order to obtain reliable data on

Table 1. Change in speed of draught animals.

Time (hr)	Speed (m/min) Crossbred oxen	Speed (m/min) Indigenous oxen
I	68	67
II	58	55
III	48	44
IV	43	40
V	40	37
VI	39	36

power output. The information on the variation in power output of draught animals during a full day is inadequate and figures quoted as average power output are often misleading. In my opinion an ox can sustain a power output of one m kg/s for each 12.5 kg body weight in the tropics over a period of 6–7 hours with 1 hour rest during the work period.

A draught animal can be compared with a motor-battery system. While the motor rating determines the power, the battery determines the work capacity or energy output of the system. Information on daily work capacity of draught animals under different working conditions and the effect of variations in work-rest cycle on daily work capacity is grossly inadequate. This information is essential for proper task design and in order to avoid accumulation of work stress in the animal.

Tasks and Implements

Agricultural operations include both stationary and tractive tasks. Draught animal power is compatible with most of the tractive tasks like tillage, planting, interculture and transport. The draught power output of a pair of average oxen is inadequate for harvesting of most of the crops. Oxen are more difficult to control than horses for intercultivation of crops. Better training to walk in a straight line can increase the utility of oxen for intercultural operations. The use of draught animal power for stationary tasks is not as common as the use in tractive operations. Limited power output, relatively high cost of equipment for transmitting power from the bullocks to the stationary machine and fluctuations in the speed of animals has resulted in a marked preference for electric motors and small I.C. engines as prime movers for stationary equipment like irrigation pumps, threshers and sugarcane crushers. Studies by Pathak and Bining (1985) have shown that draught animals continue to be maintained in smaller numbers on mechanised farms because of the economic advantages in using them for light tractive tasks.

A wide range of animal-drawn tillage and planting equipment is available in the world market. Rotary tillage is not practical with animal power. But animal-drawn mouldboard ploughs, disc and blade tools, different types of harrows and cultivators are successfully used in many countries. The often reported failure of programs to introduce improved animal-drawn tillage equipment occurs mostly due to wrong selection of equipment (emphasis on mouldboard plough in semi-arid regions of Asia and Africa is one such example), inadequate facilities for maintenance and repairs, weak extension programs and lack of incentives to improve production techniques. Animal-drawn planting equipment, both for close-growing crops and row crops, performs as satisfactorily as mechanised planting equipment provided it is properly fabricated and operated. Bullock-drawn seed drills and seed-fertiliser drills (combines) have played an important part in raising wheat yields in north India. Equipment for inter-row cultivation is available in a wide range and oxen are commonly used for interculture in sugarcane crops. But oxen are difficult to control and unless they are well trained damage may occur to the crop during intercultural operation from the implement and through trampling. It is possible to use animals for application of pesticides and herbicides. Animal-drawn equipment for application of plant protection chemicals has been developed in some countries, but it has not found wide acceptance because the equipment operated manually or with small engines is more convenient to use.

Horse-drawn harvesting equipment was commonly used in America, Australia and Europe until the tractors replaced the horses. However, for reasons of relatively low power output and reduction of speed during operation, oxen-operated harvesting equipment has not been extensively used. Animal-drawn single row potato diggers are used in limited numbers in some parts of India. Efforts have been made in recent years to supplement animal power with small I.C. engines for harvesting cereals. This is done by mounting the engine on the harvester frame to operate the cutting mechanism while the equipment is pulled by the oxen. This development has remained confined to laboratories. Animal carts and wagons are extensively used in many developing countries. Better rural roads and improvements in the design of these vehicles, particularly the use of pneumatic tyres, has enhanced the usefulness of animals for rural transport. Most of the sugarcane in north India is transported to the mills in animal carts. The weight of cane loaded in a buffalo cart is three to four times the weight of the animal.

Harness

Animals are harnessed singly, double or in greater numbers to match pulling capacity load. It is generally accepted that the pulling efficiency decreases with number of animals harnessed together. Multiple harnessing of horses using appropriate arrangements of swingle-trees was common when these animals were used for draught purposes. The oxen are mostly harnessed in pairs, using a rigid yoke attached to the load with the help of ropes or beam. Two pairs of oxen are sometimes used to pull heavy rollers for crushing clods under rainfed conditions. A pair pulls each end of the roller. In the black cotton soils of India harnessing of four to six pairs of oxen has been tried to pull heavy ploughs. In this case the pairs were harnessed in tandem and equal distribution of pulling effort between different pairs was difficult to maintain.

Oxen are hitched to the load either at the neck or at the forehead. The forehead arrangement is used in some countries of Latin America. It is unsuitable for transport work. The fluctuating and occasionally heavy vertical load at the forehead can cause serious strain to the neck of the animal. Hitching at the neck allows more flexibility in the movement of the animals and gives them a better capability to tolerate vertical loads. The usual method of applying neck load is through a wooden yoke. The surface of the yoke in contact with neck skin is smooth. Sometimes the yoke is suitably altered to provide additional surface area which rests against the hump. The traditional yoke has been considered an inadequate and a crude device by many harness designers. Repeated efforts have been made in the past to alter and improve the traditional yoke for oxen in anticipation of improvement of draught and work output. The yoke developed at Allahabad Agricultural Institute (India) in the early sixties was one of the better engineered modifications. It was padded and rested both on the neck and shoulders of the ox without hampering its movement. It was, however, heavier and more expensive. Contradictory results have been reported about the improvement in draught capacity of oxen as a result of modification of yokes. A review of the published information tends to lead one to the conclusion that the modifications incorporated so far do not significantly improve the draught capacity of oxen. A good and practical improvement in single buffalo harness for transport work has been the introduction of a back strap which helps to distribute the vertical load, exceeding 100 kg in some cases, between the neck and the back of the animal.

Reference was made earlier to the need to minimise the vertical component of the pull as it causes avoidable strain. However, some amount of vertical load is necessary when a conventional yoke is used. Without vertical load the yoke tends to slip back. In the case of collar and breast strap, harnesses commonly used for horses and donkeys, the need for vertical load is much reduced.

Measurement of Draught Work

Direct measurement of draught, speed and time is a reliable method of determination of the work output of draught animals. Strain gauge transducers have generally replaced the spring and hydraulic dynamometers used a few decades ago. Lightweight recorders are available for continuous recording of the draught in the field. It is feasible to record speed and pull simultaneously against time which would give complete information on the fluctuations in draught and speed observed so commonly in the field, the instantaneous and average rate of work and the total work done during the period of observations.

Direct measurements are inconvenient and often difficult under field conditions. Calibration of the physiological responses of an animal against work rate and work output could permit the use of parameters like heart beat and body temperature as measures of work done by it. Indirect measurement of work is a common technique in human engineering studies. Pulse rate, which is convenient to measure and record, is calibrated against rate of work. It has been observed that the pulse rate of a subject adjusts itself to the workload within a period of 5 min after which it remains steady. This does not appear to be the case with draught animals. Maurya (1982) has reported continuing increase in heartbeat rate, respiration rate and body temperature for a period of 3 hours or more.

Further, under normal conditions the heartbeat and respiration rate of a human returns to normal after a short rest and a period of 30 min is considered adequate for this. The recovery takes much longer in the case of animals and unless appropriate rest periods are allowed, residual stress will make the indirect measurements inaccurate. Information on appropriate work-rest cycle for different types of draught animals including oxen to ensure the reliability of indirect measurements appears to be inadequate.

Standardisation of work conditions is essential for indirect measurement of work output and for the determination of work capacity of an animal. A large number of variables including age, health and nutrition of the draught animal, work-rest cycle, speed, ambient temperature, radiation, altitude, topography, surface conditions, soil strength and vertical load influence the work stress development for a given draught and also the work capacity of the animal. Animal scientists and engineers should come to an agreement on the standard conditions for evaluation of draught performance of animals. The influence of the variables listed above on draught animal performance needs to be determined in order to meaningfully interpret the data generated under uncontrolled working conditions.

Selection of a suitable loading method continues to pose questions to the draught animal power researchers. The treadmill is a useful device which allows variation and control of many factors. However, it is not feasible to simulate different surface and soil conditions in a treadmill. Loading cars are frequently used on surfaced and dust tracks. Hydraulic pumps receiving power from the car axle act as loads. Some researchers have used ordinary wagons and loaded them with different weights to vary the pull. If the ground conditions are not uniform this method will not yield reliable results. Suspended weight loading is a better method but it imposes the speed on the animals rather than allowing them to adjust their speed according to load and fatigue.

Little effort has gone into the development of test tracks for draught animal power studies. A straight track requires turning of the animals and loading device at each end. A circular track offers the advantage of continuous operation and easier instrumentation. Different slopes, surface roughness and soil conditions can be easily simulated in a test track. Development of facilities to control and simulate different ground conditions needs more attention.

An overview of the work reported on different aspects of animal draught power brings into focus the importance of standardisation of research methods, particularly in respect of work conditions. At present it appears impracticable to compare and correlate the information on draught performance of animals generated at different locations under different conditions. Joint efforts of animal scientists and engineers can rectify this deficiency in animal draught research within a short time.

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Other Presentations

Draught Animal Power: Project Considerations—A Synopsis

Graeme Donovan*

THE change from animal draught to mechanical draught is a change of technique, but the initial introduction of animal traction is a change of farming system. Sub-Saharan Africa contains the largest areas remaining in the world which have yet to make the transition from hand hoe agriculture to animal draught. The transition takes place in response to increasing population pressure on land, or improved access to markets for agricultural products. These lead to a reduction in fallow periods, a change to annual cultivation, and eventually to multiple cropping. This change is a necessary but not sufficient condition for a switch from human power to animal power, which will take place when it becomes profitable to plough. This profitability is, in turn, determined by the cost relationship between hand methods and using and maintaining animals, but is also affected by workability of soils, the place in the toposequence where farming is concentrated, responses of crops to tillage, and the degree to which equipment can be used to potential capacity.

Draught Animal Components in Projects

The following are the most important points to consider for success with draught animal components in projects:

Profitability

Farmers will take up DAP only if it is profitable to them; this means raising profit per *day* of farmers' labour, not merely per *hectare* cropped. To achieve this, DAP must usually include weeding as well as primary tillage, and the value of meat from culled draught animals will be important to farmers.

DAP Costs, and Credit

Draught animals and their equipment are costly, and represent a very large investment for farmers adopting DAP. Credit is essential, from either informal or formal sources. Although it is possible to devise in-kind credit schemes (with farmers paying back in offspring from female animals), most will be in cash terms, and farmers must be in the market economy to pay back loans.

Insurance

High cost, valuable draught animals should be insured.

Supply of Animals

In the "take off" phase for DAP in a new area, special arrangements to supply enough animals may be needed. Beyond this, providing credit and letting farmers buy their own animals is the best approach.

Training of Animals

If there is absolutely no tradition of DAP in a project area, special training arrangements may be needed, but once a few farmers know how to do it, it can be left to them. It seems to be profitable to cull draught animals early for meat production (perhaps at 6 years of age), trading off the value of meat for additional training costs.

Feeding

In most cases, animals are far below their genetic potential for size and productivity because of poor feeding. Providing more and better feed is the most important factor in increasing productivity of draught animals. Research on this must treat the integrated crop/livestock system.

Health

Farmers must have ready, reliable access to all the vaccinations, sprays, dips and drenches necessary to combat diseases and pests in the project area. Draught animals are more susceptible to accidents

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than producing livestock, and their tiring work makes them more sensitive to disease. Therefore improved *curative* veterinary services may be needed.

Blacksmiths

Training for blacksmiths, and credit to improve their equipment, are important for supporting DAP.

DAP Equipment Design

The really important, adaptive cost-cutting design work is best done by commercial firms in a competitive situation without government interference. Further work is needed on seeders and toolbars.

Draught Animal Power in Bangladesh: An Appraisal

A. M. M. Tareque*

AGRICULTURE is the main occupation of the people of Bangladesh, employing 61.3% of the labour force. This sector directly contributes around 46% of the gross domestic product. In Bangladesh, farmers are wholly dependent on animals for land preparation. The animals are also used in carrying and threshing of harvested crops, in extracting juice from sugar cane and oil from oil seeds, in transportation of commodities, etc. It appears that for many years to come there will be nothing to replace bullock power in the country considering the socio-political, economic, topographic and climatic factors. It is necessary, therefore, to carry out further research to ensure that draught animal power is improved.

Draught Animal Population

The total number of cattle in Bangladesh is estimated at 20.5 million, of which 49.4% (10.1 million) are female cattle. The total number of male cattle is estimated at 10.4 million, of which 7.6 million are aged 3 years and above. The total number of female cattle used for agricultural work is estimated at 3.3 million. The total number of cattle (both male and female) used for agricultural work is estimated at 10.9 million.

The total number of buffaloes is estimated at 0.47 million. The number of buffaloes (both male and female) used for agricultural work is 0.32 million.

The total number of cattle cum buffalo (both male and female) used for agricultural work is estimated at 11.2 million. The total temporary cropped area of the country is estimated at 31.2 million acres. Therefore, the area per pair of work animals is 5.6 acres (Agri. Census 1977).

Status of Draught Animal

Land preparation of 8.0 million acres of direct seeded Aus rice, 1.5 million acres of jute land, and 4.5 million acres of deepwater rice lands needs to be completed within 1 month, from mid March to mid April, to attain higher yields. But in almost all years frequency and quantity of rainfall adversely affect these operations, taking more days for land preparation. Under these circumstances, if a pair of bullocks take 60–64 hours/acre (Hussain and Tareque 1984) for the preparation of land, with five tilling and two laddering operations for rice cultivation, and if we assume that a pair of animals work for 6 hours/day, then it will take 10 days without any break to prepare an acre of land. If we consider the total number of draught animals available for land preparation during the season then the total number of days stands at about 30, which fairly agrees with the demand. But practically this may be impossible. In this case improvement in field efficiencies of draught animals will ensure adequate land preparation.

The power production per animal can be observed from an estimate by Hopfen (1969): bulls and bullocks 0.375 hp/head; cows 0.225 hp/head; and buffaloes 0.375 hp/head. In Bangladesh on an average each animal produces 0.33 hp (Mettrick 1976) compared with 0.5 hp/animal in other South and Southeast Asian countries. The low draught power of cattle in Bangladesh is mainly due to the poor health of the animals and poor design of the yokes. Hopfen (1969) pointed out that the pulling power produced by the animals was directly proportional to their weight, and nearly equal to one-tenth of the animal weight. Small animals develop comparatively more power than the larger members of the same species. The relative draught efficiency of smaller animals is better because their line of pull is lower, i.e. the more accurate the angle of pull that can be made with the ground, the less is the power required to pull the implement.

Land-Use Pattern and Availability of Feedstuffs

There is no specified pasture/grazing land in Bangladesh. The general status of the availability of feeds in terms of dry matter can be seen from Table 1. Livestock are mostly reared on crop residues such

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Table 1. Availability of feeds and fodder in Bangladesh.

By-product	Quantity available '000 tons	Dry matter %
Paddy straw	26253	90
Wheat straw*	342	90
Maize stover*	5	90
Joar stover*	4	90
Barley straw*	13	90
Pulse straw	238	90
Rice bran	1276	90
Wheat bran	3	90
Oil cakes	184	90
Sugarcane:		
Tops*	1534	28
Bagasse*	2001	50
Molasses	220	80
Fruit leaves*	492	20
Fruit stems*	107	82
Sweet potato leaves	1155	20

* Unconventional feedstuffs.

as straw; a small quantity of green grasses is available from homesteads, roadsides, tree leaves, embankments, etc. The deficiency of dry matter was estimated to be around 12%, if total availability was considered to be used by animals, but around 50% if other losses were considered. The protein deficiency was also around 80% (Tareque 1983).

Effect of Different Body Weights

Factors affecting better land preparation may be type of power source, type of ploughs (shape, size and weight), soil types, moisture content of soil, season and time of ploughing, speed of ploughing, operator's skill, age, sex and height of draught animals, training and general health condition of the draught animal. Considering factors for optimal power production, the efficiencies of draught animals can significantly be improved, ultimately reducing the number of draught animals which will help bridge the gap of feeds and fodder deficiency in the country. It has been observed that due to the use of cows for draught purposes the milk yield, calving interval, fertility, etc. are significantly affected.

A field study was carried out in the Bangladesh Agricultural University farm in order to determine the energy and time requirement for complete land preparation for rice cultivation using bullocks of different body weights (Hussain and Tareque 1984). Results showed that the lower body weight and smaller size had better draught efficiency than that of other pairs of higher body weights and sizes. This was in agreement with the observation made by Hussain et al. (1980).

Recommendations

1. Work should be carried out to determine the effect of draught on feed intake, nutrient requirements and nutrient metabolism.
2. A feeding system should be developed based on the type of work, type of animal, and type of feed available in the region.
3. Research programs should be drawn up to study the overall draught animal power efficiency of bullocks vs. bulls, buffaloes vs. cattle, males vs. females, and the effects of work on reproductive parameters, and physiological and nutritional parameters.

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