Draught Animals in Rural Development

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Draught Animals in Rural Development

Proceedings of an International Research Symposium, Cipanas, Indonesia, 3–7 July 1989

Editors: **D. Hoffmann, J. Nari and R.J. Petheram**

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Foreword

The estimated one billion draught animals throughout the developing world provide vital power, transport, milk, meat and security to millions of rural families. Considering the importance of animal traction, insufficient emphasis has been given to innovative research to improve the working efficiency, nutrition, or the overall productivity of draught animals; and this in a world increasingly conscious of environmental dangers and the need to become less reliant on fossil fuels.

For some years ACIAR has, within its Animal Sciences program, commissioned research projects associated with draught animals, and sponsored a major international workshop in 1985 to help set a research agenda for the ensuing years. Dr J.W. Copland of ACIAR was the architect of this subprogram, which has recently been made the responsibility of Dr Denis Hoffmann who joined ACIAR in early 1989.

This second major conference on animal traction was organised to review the progress and relevance of research on draught animals since 1985 (with particular reference to the ACIAR subprogram), to review global research priorities, and to recommend future directions for research for the ACIAR Draught Animal Power subprogram. This subprogram includes a range of projects with much wider application than to draught animals alone.

We hope that the conference and this publication will stimulate further interest in the continuing important role that draught animals have to play in developing countries, and that further research will address the problem areas identified by the participants.

G.H.L. Rothschild
Director
ACIAR

Editors' Preface

Collaborative international research implies endeavours, not only in the sphere of science, but in communication and cross-cultural exchange. This is particularly valid in the case of draught animal production, where the wide variation in the history and utilisation of animals for power across the world gives rise to a valuable range of knowledge, skills and resources that could be brought to bear on this important field of livestock research.

At this stage of research, Australian scientists have much to learn from other countries about animal working practices and the biology, economics and mechanics of draught animal power (DAP) systems. Australian research may, in turn, have much to offer other tropical countries, with similar livestock and climatic conditions. Our learning process was significantly enhanced and guided by the Proceedings of the First ACIAR Workshop on Draught Animal Power, held in Townsville, Australia in 1985. That workshop dealt largely with the state of DAP in various regions and of knowledge in some main disciplines.

At this Second International Workshop, the stress has been on *research* on DAP. Participants were taken further into the field of animal traction, with sessions on a wider range of topics than at the first Workshop. One of the main messages from the presentations has been the inherently multidisciplinary nature of DAP systems and hence the importance of an appropriate mix of disciplines in research.

The proceedings of this Symposium reflect something of the balance of disciplines currently involved in DAP research, perhaps with some notable omissions, such as that of crop and soil scientists.

Workshops are intended primarily as a learning mechanism. In addition to summarising the results of Group Discussion Sessions at the meeting into a series of Recommendations, an effort was made to evaluate the workshop itself and to seek participants' opinions on the conduct of future symposia. At the conclusion, participants were asked to complete a questionnaire, covering topics from their reactions to the official sessions, to technical standards, visits, facilities, organisation and management.

Aspects of the Symposium that were rated especially highly were the Opening Ceremony, the village visit, video films of DAP research and the poster displays. One main lesson learned was that the program was too packed — more time was needed for both formal and informal discussion. A large common room would have helped in this respect. Many felt that full papers (rather than abstracts) should have been distributed to all participants, despite the cost and weight of paper involved. Other comments suggest that more emphasis should have been placed on the effective delivery of papers, with insistence on better quality visual aids. The assistance of Mr Paul Starkey who prepared the evaluation sheet is much appreciated.

D. Hoffmann J. Nari R.J. Petheram

Acknowledgments

ACIAR extends gratitude to a number of people in Australia and Indonesia for their part in organising and ensuring the success of this important symposium. Particular thanks are due to the workshop organiser, Dr John Petheram, secretary Mrs Kaye Griffiths, of James Cook University, and to Drh Jan Nari and Dr Benny Gunawan and their Indonesian committees who did excellent work. Special thanks also to Mr Djarot Soekresno and Mr Kosasih, and the many Indonesians who efficiently mounted the displays, organised transport, field trips, cultural events and contributed in other ways towards a most successful and productive conference. The support of Dr Jim Hogan of CSIRO and of Mr John Perkins of the University of Melbourne was invaluable. ACIAR's liaison officer in Jakarta, Mr Andrew Elms, provided substantial input before and during the symposium.

We are especially grateful to the following people who officiated at the opening ceremony of the symposium: Dr Benny Gunawan, organising committee chairman, Dr Denis Hoffmann, representing the ACIAR director, Mr David Irvine, Deputy Australian Ambassador in Jakarta, and Dr Soetatwo Hadiwigeno, Director-General of AARD.

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Recommendations

Introduction

THE first ACIAR-sponsored international workshop on Draught Animal Power was held at James Cook University, Townsville, Queensland, Australia, in July 1985. At this second workshop, there was a recognition that much had been achieved in the 4 years since the first conference. There had been a worldwide increased awareness of the significance of the role of draught animals and a better understanding of the problems within the draught animal systems. However, many of the recommendations made at the first workshop are just as relevant today as when they were made 4 years ago.

In the course of the Workshop, formal discussion sessions were held on each of the major areas of DAP research covered, except Economics research. Participants were allocated to three groups for these discussions and each group developed a set of **recommendations** for future research on the particular topic. At the conclusion of the Workshop, the recommendations of all subgroups were summarised into the set of recommendations, which follow:

1. General

(i) Single-discipline research will be needed in various areas of draught animal power (DAP) research. Priorities for disciplinary research would be determined by the needs and economics of the problem or would be derived from the findings of the farming systems research studies at the sites selected to represent important DAP systems.

(ii) Studies should be continued to determine the economic and social impact of proposed technologies or interventions aimed at improving the contribution of DAP to farming systems.

(iii) Effective draught animal research requires strong bidirectional links between station-based and field-based researchers.

(iv) Sustained support for research in all areas of agriculture requires researchers to undertake economic impact assessment studies. Such studies should be a part of research on draught animal power.

2. Farming Systems Research

It was generally agreed that FSR is an appropriate basis for the study and development of draught animals for production. In a classical FSR approach, national priorities and secondary data should be used to select research sites, followed by the description of sites (diagnosis of constraints), design of possible improvements, and testing on farms (and research stations). FSR also encompasses the transfer of tested technology to extension agencies and the transfer of information on nontechnical constraints to policymakers. The ideal interacting group is seen as farmers, local leaders, extension and research scientists, including appropriate specialists.

(a) Description of FSR Sites

(i) The information (data set) needed to describe each research site will vary with different investigations, but should cover the land, the farmer, the animal and the crops, in sufficient depth to define constraints in the system.

(ii) In describing sites, there is a need to develop appropriate methods to record and analyse both quantitative and qualitative data relating to DAP within FSR, e.g. standard measurements of work output, soil conditions, animal feeding practices, etc.

(iii) Descriptions of FSR sites should be published in accessible, digestible form.

(b) Farm Testing of Ideas to Improve DAP System

(i) Farm testing of ideas to improve DAP systems is seen as an essential component of DAP research. Farmers need to be involved from the outset both to help define problems and to assist in the design of farm trials.

(ii) Specialists should also be involved, where appropriate, in defining constraints and in the design and conduct of farm trials.

(iii) Care should be taken in the definition and selection of farmer groups to ensure benefit to the desired target groups.

(iv) In planning farm research, arrangements should be made to ensure sharing of risk and compensation for farmers, e.g. for loss of animals or crop yields.

(v) Communication of ideas to be tested is a vital component of on-farm research, e.g. through video material, or the organisation of tours by farmers.

(vi) Results of farm trials should be well documented (even where these fail to produce technology acceptable to farmers), and should include analysis of economic and social impact.

(c) Management of FSR

(i) There needs to be an institutional framework for FSR in which the farmers and their regional and national bodies can influence decision-making by corresponding research and extension bodies.

(ii) Methods to motivate scientists to become involved in FSR should be sought. Support is needed for channels to ensure publication of results of on-farm research.

(iii) Currently, the number of scientists trained in FSR theory and methods is negligible compared to the person-years of training expended on single disciplines. In-service training in FSR is needed for research management personnel and scientists.

3. Nutrition

(a) Measurements of General Nutrition

(i) To verify the adequacy of existing knowledge of feed and nutrient requirements, in particular DAP systems, an attempt should be made to prepare a feed-year strategy, i.e. to match feed supply with nutrient demand throughout the year including work, calving, lactation, etc. Further nutrition research should be planned to fill any gaps in knowledge so revealed.

(ii) To achieve progress in research under (i), inputs are needed from groups involved in improving forage production and provision of supplements, as well as those interested in improved feed preservation and utilisation.

(iii) In recognition of the increasing dependence in many regions on the working female for draught power, it is recommended that the focus of nutrition research should be on the female animal.

(iv) Specific nutrients required by the working muscles and lactating mammary gland should be identified and quantified and the partitioning of these nutrients between these two tissues in the working lactating animal determined.

(v) The effect of levels of work, current nutrition and body reserve nutrients (liveweight fluctuations) on reproduction should be determined.

(vi) A systematic classification of locally available feedstuffs in terms of its value for particular functions (e.g. work, lactation, etc.) should be undertaken, i.e. feed should be classified based on its potential for supplying amino acids, glucogenic compounds and long-chain fatty acids.

(vii) The need is recognised to validate, on farms, the results of nutrition research on stations.

(b) Measurement of Energy Expenditure

(i) The need is seen for continuing research on energy transactions in working animals.

(ii) Two types of energy study are envisaged: (1) sophisticated experiments conducted in a few laboratories, and (2) simpler energy measurement in experiments in numerous locations.

(iii) Sophisticated studies should aim to define energy use in components of work, conditions of stress, superior animals and development/calibration of simpler methods.

(iv) Simpler measurements could include change in weight and condition score in relation to workload and feed intake.

(v) Links between workers making simple and sophisticated measurements should be sought and information exchanged.

(vi) Data reported should include age, physiological state of animals, body weight, condition score, body composition, and environmental data.

4. Engineering

(i) Engineering research into tillage implements should concentrate on the modification of implements to suit new and local conditions. Transfer of existing technology should be investigated before new research commences.

(ii) The need exists to consider modification for use with DAP of implements for postharvest technology, pesticide application, manure distribution and rolling cultivation, in certain farming systems. Other systems are still at the stage of introduction of rudimentary ploughs.

(iii) To develop better DAP tillage systems for greater productivity, engineers should work closely with soil, plant and animal scientists and consider problems of animal-powered work in both wet and dry soils.

(iv) The meeting warned about loose definition of the term 'draught,' which is a property of the implement/environment/operator and not of the animal which supplies the power for work.

(v) Knowledge of the capacity of animals to provide power is seen as important information. Development of simpler and cheaper measuring equipment is seen as desirable to permit achievement of this goal.

(vi) Measurements of soil physical properties are important in specification of draught. Simple methodology needs to be described.

(vii) Research into tillage practices and maintenance of desirable soil properties was supported.

(viii) The meeting favoured technology transfer in harness design rather than research. Cost, comfort and efficiency were seen as the main criteria in harness selection.

5. Animal Breeding and Genetics

(i) Breeding research related to DAP should have simple objectives.

(ii) Parameters for breeding for DAP cannot be clearly defined. Breeding should concentrate on meat and milk production and fertility with selection within those animals for work.

(iii) Choice of genotype and size of animal will be determined by social and environmental factors at village level.

(iv) Assessment should be made of the impact on draught power of cross-breeding for increased milk production.

(v) More applied research should be carried out to identify causes of low fertility in draught animals, including problems with supply and quality of bulls.

6. Animal Health

(i) There is an urgent need to define the incidence of disease among draught animals in specific areas. Attention should be given to subclinical as well as clinical diseases which affect productivity.

(ii) The economic significance of identified diseases should be assessed and included in submissions to policymakers. Practical solutions to the simple animal health problems faced by farmers are needed, in addition to strategies to control the more serious diseases (which are less common).

(iii) Institutions capable of obtaining accurate data should be identified and supported in disease survey and control work.

(iv) These institutes should use detailed protocols and engage in multi- and interdisciplinary studies.

(v) Efficient extension services are also essential for fully developed epidemiological studies.

7. Training

(i) It was considered that there is no need for research on methods of training animals.

(ii) Organisations engaged in draught animal training programs for extension services to farmers should arrange to interchange information on methods and curricula.

8. Economics

Because no discussion session was held at the workshop specifically on economics research, some issues related to economics and DAP research were covered in a short paper by Prof Frank Anderson, an economist with many years experience working in draught animal research. The text of Prof Anderson's paper follows:

Effective draught animal research requires strong bidirectional links between station-based and field-based researchers. The development and maintenance of these links is facilitated when key researchers are involved with and responsible for both applied (i.e. mainly station-based) and adaptive (i.e. mainly farm-based) research. Such arrangements help address potential difficulties associated with perceived differences in the status and importance of work in these situations.

In all instances research protocols should be prepared, discussed, agreed upon and used as the blueprint for the draught animal research. Revision of protocols will be both inevitable and essential as advances are made and as circumstances develop or change. An annual in-house review of all draught animal-related research is an efficient way of ensuring the appropriate revision of protocols. Such in-house reviews can be a powerful vehicle for staff development and, when properly managed, can help foster team spirit in the research effort and help avoid elitism and possible bias in the research resource allocation and control process.

While important gains in the productivity and efficiency of smallholder farming systems are achievable through research focused on the draught animal subsystems, these gains will be increasingly difficult to sustain unless proper account is taken of the complex interactions between the cropping and animal subsystems. Thus, researchers concerned mainly with draught animal subsystems will increasingly be required to collaborate with their counterparts in crop research and to seek through this collaboration to achieve greater overall impact from the total research effort. The tradeoffs between goals which are often only implicit when separate (disciplinary) research is the norm are more likely to be made explicit in the context of open collaborative research.

Effective draught animal research requires researchers to adopt and adhere to the tenets of the farming systems approach to research whereby farmers' circumstances and goals are primary determinants of research. Where the institution adopts the farming systems approach to research as an operational philosophy, the backward linkage from the adaptive to applied research is stronger than in situations where only teams within the larger research institution adopt and use the approach. In this latter case the forward linkage between the adaptive research team and the target farming communities is relatively stronger and the adaptive research team has less and usually quite limited impact on the applied research portfolio of the institution. When field teams are constituted to undertake the adaptive research and the teams include only limited contributions from station-based disciplinary specialists, they will tend to concentrate their efforts downstream and seek to achieve significant local impact. The opportunity costs of focusing on downstream impact rather than attempting to influence institutional actions — the upstream effect — will be substantial if, as is often the case, the research findings are applicable in areas other than where they were tested.

Involvement in field research is a necessary but not sufficient condition for researchers to be able to discriminate between interesting and useful research. Researchers are a scarce resource in most developing countries so it is imperative that wherever possible, properly targeted, problem-oriented research is undertaken.

An important tradeoff confronts research administrators concerned with draught animal research. Effective adaptive research requires a critical mass of researchers to be involved in a target area for a sufficient period of time to elicit an understanding of the essential functional features and the dynamics of the system. Because of the diversity of draught animal systems, even within any one country, research administrators are often required to dilute the research efforts at any one site in order to have an active institutional involvement at more sites than is practicable or appropriate. There are no established rules for determining the number of sites at which adaptive research should be undertaken. However, the scale and duration of work at each site must at least ensure that both forward linkages to the local farming community and backward linkages to the parent research and development agencies are effective.

It follows that research budgets make proper allowance for these forward and backward linkages, in particular that adequate provision is made for field visits by station-based researchers and for collaboration with other relevant research and development agencies. Inadequate funding is a major constraint on the effectiveness to date of adaptive research.

Numerous systems-level studies in a number of countries have demonstrated the importance of draught animals in smallholder farming systems in Asia and Africa.

Many useful interventions for use in these draught animal systems have been devised and tested. Thus far, however, inadequate attention has been paid by researchers to assessing the impact (both potential and actual) of these interventions. Increasingly, sustained support for research in all areas of agriculture will require researchers to undertake such impact assessments. Substantial methodological issues must be addressed before they can be done as a routine in regard to draught animal systems, mainly because draught animals produce principally intermediate and not final products on farms.

These impact assessments will be required to be done at both the micro (i.e. farm) and macro (i.e. regional or national) levels. In all cases, results will be enhanced if time series data are available from a significant number of farms in the targeted farming areas. At this time there is a paucity of such data from all but a very few of the farming systems where draught animal research has been or is being done.

Section 1

Introductory Papers

Draught Animal Power to 2020

R.S.F. Campbell*

THE holding of this workshop reflects the international importance of draught animal power (DAP) in today's world. Approximately 2 billion people depend on DAP, and nearly 50% of the cultivated world needs draught animals (Ramaswamy 1985). What will the world need in 2020? The answer is much more in food crops and animal protein, increased farmer income and improved agricultural technology to ensure sustainability into the future.

The People Factor

One thing is certain. In 2020 there will be many more people. Demographers estimate that food production must increase to meet the needs of 7 billion people globally, including 3 billion in Asia. Beyond 2020 is a period of great uncertainty (Fig.1).

Draught animals will help to produce a significant amount of the food required but they alone cannot do the job in the tropical and subtropical world without vast improvements in farming systems generally.

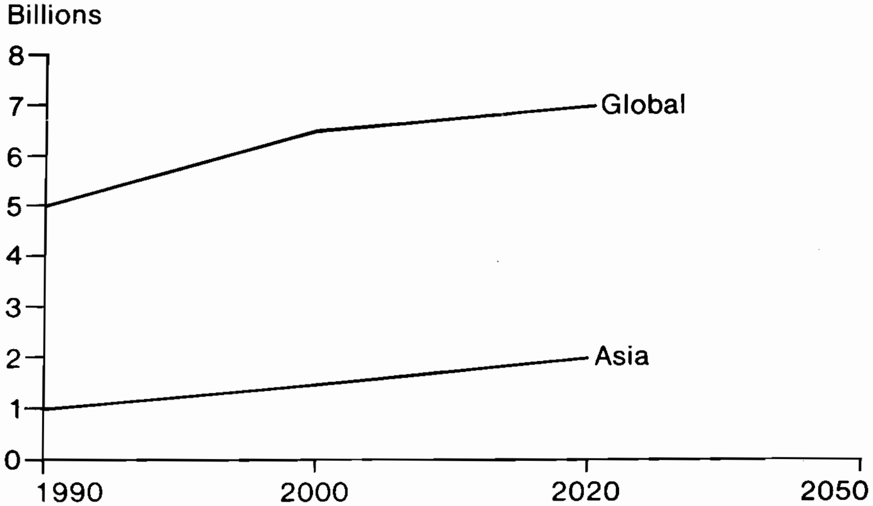

Fig. 1. Demographic trends from 1990 (Unofficial Assessment, Population Division, U.N., New York).

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At the recent International Buffalo Conference in Delhi, the following folk song was quoted (Acharya 1988):

Come my beloved
Let's buy a buffalo
For then
We too shall be opulent.

To the modern small farmer this must sound optimistic. Not many draught animal (DA) rearers reach their full cash flow potential.

DA → crops → income
manure → income
calf → income
tillage → income
transport → income
rent → income
milk → income
meat → income
capital gain → income
banking → security
status → security

The farmer may be aware of this potential though he does not achieve it. Calving percentages and growth rates are often low, crop establishment poor and many extension services, which could be the source of help, still lack the capability to improve the farmers' management.

The Animal Factor

People who count animals are not very optimistic, as a recent review has shown that livestock numbers sometimes decline (Table 1).

Table 1. Livestock population and productivity in Indonesia ('000).

	1974–76	1982	1983	1984	% change (83–84)	Required increase
Cattle	6211	6594	6650	6800	+ 0.2	1.18
Buffalo	2381	2513	2500	2391	− 4.0	1.03
Goats	7252	7891	7900	7910	+ 0.1	—

From: Review of the Livestock Sector of Indonesia (ADB/GOI 1986).

The human population–food production equation is only one problem to be faced in the next 30 years. Within each country, land pressure is increasing as a result of urban and industrial expansion, and at the agricultural level holdings will contract as subdivision takes place within family units. None of these trends is likely to increase productivity of animals or crops, unless special measures and research are geared to cope with inevitable future trends.

Constraints to Agricultural Production

To the constraints on agricultural production through reduction in cultivable land can be added such effects as inadequate production caused by low growth and calving rates of cattle and buffalo (Partoutomo et al. 1985). Poor crop productivity and natural and people-induced climatic stresses may also have major effects on animal production. This is a depressing prospect, even before we start to consider the possible effect of disease.

To match food production to human population increase in the next 30 years is a critical matter and may not be achieved. The initial euphoria of the Green Revolution in Asia has been followed by a more sober consideration of human requirements in the future.

There are, of course, regional differences. Africa has its own environmental and political problems that can only be solved by Africans. In Southeast Asia, blessed generally with a sympathetic climate, the problems are at present more demographic than environmental, though floods, storms, land degradation and pollution through industrialisation are continual threats.

Is Draught Animal Power Enough?

In 1989 we should consider if draught animals will be equal to the task of supplying the power needed to increase crop production to the level required in the 21st century. Although an essential contributor, it is not capable of meeting the demand for agricultural products alone. What then are the alternatives?

Tractors powered by oil are the obvious current alternative source of power in agriculture. Some indication of their use has been given by Watanabe et al. (1985). Reasons for the increases in tractor use shown in Table 2 vary according to cropping methods, availability of oil and other factors.

Table 2. Tractors in agriculture in East Asia.

Country	No. in 1985	% increase (75–85)	No./ha
China	873000	141	9.0
India	607773	167	3.6
Indonesia	12033	32	0.8
Malaysia	11400	106	10.6
Philippines	19500	61	4.4
Sri Lanka	27374	75	25.0
Vietnam	40000	436	6.5

Whether this level of engine power can be sustained, let alone increased, is doubtful. Not only will oil tend to become more expensive to a degree that is unpredictable (Fig.2) but the maintenance of tractors adds costs and levels of technology which the small farmer and the developing country may find difficult to support. Mechanisation, as always, brings social costs to rural communities; invariably there is loss of animal rearing skills and the income or bank which animals generate.

While credit may be required for either tractors or draught animals, and both can yield revenue from crops or rent, only ruminants reproduce. Several studies emphasise the regional economic advantage of draught animals over mechanised agriculture (Anon. 1986) and even in a small lowland rice unit more than 50% of family income may be derived from livestock. Javier (1978) considers that the place of livestock on small-scale farms is assured even with the advent of mechanisation. Sixty percent of the annual production of digestible feedstuff is not useful directly as human food, but may largely be utilised by livestock (Javier 1978; Devendra 1985).

A certain amount of misinformation occurs in the literature relating to draught animal systems, such as: tropical climates only support grasses of low nutritional value, cause reduced growth and fertility and disease. In fact, a myriad of tropical food plants, including legumes, can be made available, infertility is caused as much by mismanagement (e.g. lack of bulls) as climate, and disease may be minimal and easily contained if it is accurately diagnosed. It is important to understand, however, that considerable differences may occur between districts or even farms, which only close cooperation between farmers and skilled research or extension workers can identify and correct.

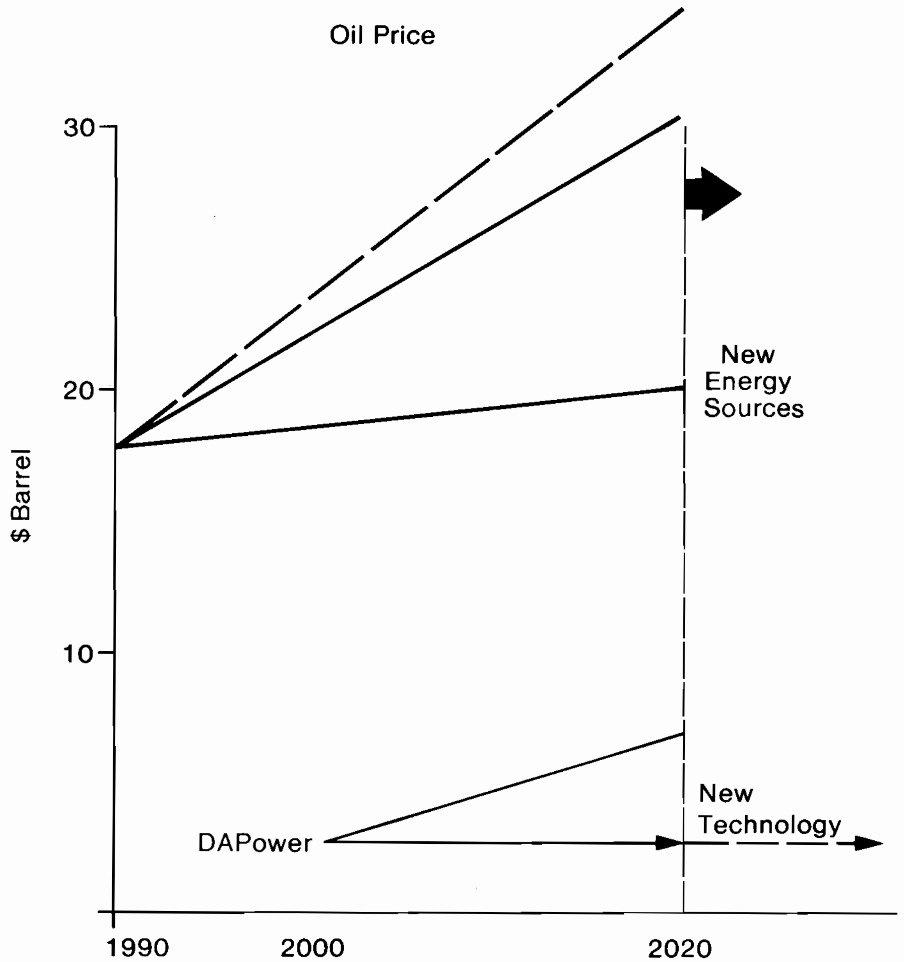

Fig. 2. Theoretical relationships between draught animal resources and oil as an energy source. ——— = potential trends in draught animal numbers and oil prices.

Draught Animal Health

In no aspect of the system are regional differences more evident than in animal health. Buffaloes reared in the uplands of Indochina may suffer severe losses when exposed to work and trypanosomiasis in lowland rice-growing areas. Nilotic cattle suffer annually from the twin stresses of malnutrition and internal parasitism and may also be exposed to pathogens such as ticks, tick-borne diseases and viruses. Elsewhere animals are relatively free from infection problems.

Until accurate information is available on the health status of draught animals in each region, we cannot assess the effect of diseases on the total system. This requires a proper analysis of the possible effects of infection, infertility and malnutrition. Technology is already available in veterinary science to diagnose, prevent or treat most of the significant problems of animal health, but our knowledge of their exact regional status still falls far short of national needs in all tropical countries. Despite the enormous advances in our understanding of animal disease, veterinary services are rarely adequate to carry out the epidemiological field work required. Governments must make a conscious decision to provide the resources if they wish to achieve maximum livestock output.

Objectives for the Draught Animal System

In the medium term, there are two imperatives in the tropics:

(i) Increase food production to match population growth where food implies energy sources and animal protein, minerals and vitamins.

(ii) Increase farmer income to ensure some prosperity and stability in the agricultural sector.

Where these objectives cannot be fulfilled the result could be catastrophic.

Draught animals will not let us down but will there be enough of them, and will they be equal to the task? Agricultural technology for the future will need new ideas and new ways or producing food as single or multiple crops. Now is the time to develop them because time is running out. Scientists, like politicians, often lurch from election to election, from crisis to crisis, from conference to annual conference, when we need agricultural quantum leaps, a series of green revolutions for the 21st century.

There is no shortage of technology to apply to agriculture and animal production (Smith 1988). Crossbreeding, embryo transplantation, genetic engineering of animals and plants, will all have their role to play if they can be delivered efficiently at field level. They will not succeed if motivation for conscientious and sound work with farmers by research and extension services is still weak because we do not invest enough, or promote incentives for such work.

When the small farmer is offered an obviously good deal he will take and apply it. An example is seen in the enthusiasm of farmers in West Timor for simple ploughing technology, which can fulfil both of the agriculture imperatives of increasing production and income.

The Draught Animal Environment in 2020

You do not need to be a scientist to know that the world's climate is changing. The daily newspapers tell us. International conferences are being held urgently to decide what to do about the greenhouse effect. Unfortunately there are limits to what can be done. We have created an uncomfortable environmental bed and our grandchildren must lie on it.

Geographers are careful to avoid precise estimates the greenhouse effect will have, but it seems certain that, in the tropical belt, mean temperatures will rise 1-2C°, rainfall may increase and, because of polar changes, there will be a rise in sea level. Extensive agricultural areas in Java, Sumatera and Kalimantan, which are dependent on tide water irrigation, will develop salinity problems and rice production will be impaired. It is difficult for animal scientists to make predictions for this scenario, but perhaps it will stimulate a preference for buffaloes over cattle or on the other hand, like the sugar producers of north Queensland, coastal Indonesian farmers may decide to diversify into aquaculture (Edwards et al. 1988).

The greenhouse effect, now with us, is the ultimate example of sophisticated technology going wrong. Industrialisation in the developed world and deforestation in the tropical belt are combining to degrade the global environment and cause serious difficulties into the future.

Future Draught Animal Systems

It has been suggested that *without radical reform*, publicly funded research and extension are unlikely to meet the needs of small resource-poor farmers. Conventional research and extension may be inadequate (Sagar and Farrington 1988). Greater interaction between the technologist and the farmer should be encouraged as the latter has much to contribute to an increase in production of both animals and crops. The trained village community, working with the research team, may be the way to success. Such an approach, which has been called participatory technology development, allows a diversity of methods, according to local circumstances. It will still rely heavily on the advice and knowledge of scientists, who may be based on experimental stations or laboratories.

It is a brave person who attempts to predict the role of draught animals up to the year 2020, but it would be a foolish one who ventures to predict their role through the 21st century, which must be a time for the development of new energy sources if our social structure is to survive. Whether animals and oil will be reinforced by nuclear fusion, fuel cells, solar or wind energy, or other forms of agricultural power, is still uncertain but new methods must be found to support and feed the human race. The future role of the draught animal system will depend on those developments (Fig.2).

Draught animals will be with us for many years, but they must become more numerous, better managed and healthier than their ancestors of today. They should become multipurpose, support more complex and stable cropping systems, breed more efficiently, and generate more money for their owners. If they do not, the tropical world will be facing disaster. This workshop can be a watershed in the development of more productive draught animal systems.

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Overview of the ACIAR Draught Animal Subprogram

J.W. Copland and Denis Hoffmann*

ACIAR established in 1982 two livestock programs, Animal Production and Animal Health. The two were subsequently combined into a single program titled Animal Sciences. Since 1983, the focus of activity has been to establish a program that was relevant to Asia, and one in which Australia had a strong research capacity. To assist ACIAR in identifying the priorities for research in Draught Animal Power, a workshop was held at James Cook University, Townsville, in 1985.

The workshop in Townsville demonstrated the importance of draught animal power (DAP) in the Asian region, and identified certain areas where Australia had a research capacity and a common interest which could address several research priorities relevant to improving the efficiency of DAP. As a result, a Draught Animal Power Subprogram was established, and became the largest subprogram in the ACIAR livestock program characterised by a multidisciplinary approach. The total expenditure of the subprogram was $6.6 million over 4 years. The time has come for this subprogram to be reviewed, which is one of the objectives of this workshop.

We are sometimes asked what comparative advantage we have in the area of DAP research, given that Australia has a highly mechanised agricultural sector. At the turn of the century, Australia relied on draught animal power to bring in the wool clip and wheat from the 'outback' or countryside. The animals used were bullocks, camels and horses. In fact the wild camel population of Australia is a direct result of Australia's needs for animal draught power earlier in this century. We now export camels to Saudi Arabia as racing camels.

Australia, in collaboration with its partner countries of Asia, has the potential to contribute greatly to the well-being of the smallholder farmers in many countries. The first workshop on DAP identified several research areas where Australia could contribute, which can be summarised as follows:

- *Animal Production* — Including animal nutrition, reproduction, livestock management and the utilisation of animal by-products.
- *Animal Health* — Identification of the causative agents of diseases, epidemiology of diseases, the establishment of control measures, the prevention of disease, and the cost-benefits of control measures.
- *Farming Systems* — Identification of the biological, economic, and social interactions of DAP in agricultural production systems.

These three research areas are active today in Australia, albeit in a different production context, and are reflected in the current subprogram.

The catalyst in establishing a major thrust in DAP was the depth of the Australian research base and the presence of the Graduate School of Tropical Veterinary Science

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at Townsville. This school has the capacity to draw on Australian and Asian research skills to address relevant research priorities of livestock in the region.

ACIAR has supported research on DAP because the draught animal falls between two sectors, the livestock and agricultural sectors, and to a large extent has been ignored by both. Draught power has a critical, although often an underutilised, role in the agricultural systems in Asia. Animal power is of major importance to Asia, and certain projects in the subprogram are of considerable importance to Australia, hence there is a mutual benefit component which is often characteristic of ACIAR projects.

The 1989 workshop will bring out the highly integrated aspect of the animal role in agricultural production systems. The bulk of DAP is used by the smallholder farmers of Asia. In countries such as India, due to social and cultural factors, milk is a highly valued commodity attracting considerable research support, yet it is thought to be only a by-product of the need to supply bullocks for draught for agricultural production.

Roles and Benefits of Draught Animals

The introduction of mechanisation was thought to severely limit the importance of animal draught power, and questioned the need for further research on improving animal power efficiency. Mechanisation is making an impact on the population of draught animals. For example, in Malaysia, where draught animals are relatively unimportant, their numbers have significantly decreased, whereas in India draught animals continue to be important in spite of mechanisation.

The replacement of draught animals in India has been estimated to be around 12–16 bullocks for each tractor introduced. However, the actual replacement is in the order of 3–4 animals/tractor. One reason for the importance of the draught animal is the decrease in size of landholdings, the inability of tractors to meet all the requirements for crop production, and the need to have readily available draught power capacity for tillage at the break of the seasons. These factors have decreased the replacement effect of mechanisation. For the next 20 years, at least, draught animal power is likely to be important in several countries of Asia.

The need for sustainability in agricultural production and the environmental issues have given added support to the continued need for draught animals. The requirement for deep ploughing, possible with tractors, has been thought to have negative environmental implications in some countries. On the other hand, draught animals are relatively benign in an environmental sense, and in fact animal manure contributes to the productive capacity of the farmland.

The Draught Animal Power Program

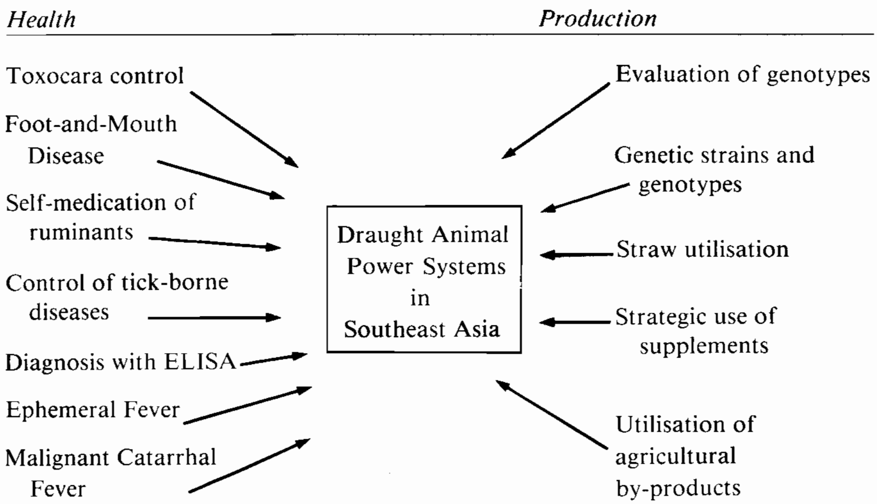
Animal Production

1. The evaluation of different buffalo genotypes for draught, meat and milk production. Countries involved in the project are the Philippines, Indonesia, Malaysia, Thailand and Sri Lanka.
2. The genetic identification of strains and genotypes of buffaloes in Southeast Asia. Countries involved in the project are the Philippines, Malaysia, Indonesia, Thailand and Sri Lanka.
3. Research into technologies for increasing the efficiency of straw utilisation by cattle and buffaloes for growth, reproduction and lactation. India.
4. The strategic application of supplements for improved milk production. India.
5. Multidisciplinary studies of draught animal power systems in Southeast Asia. Indonesia.
6. The utilisation of agricultural by-products by large ruminants. Thailand.

Animal Health

1. The life cycle of *Toxocara vitulorum* in buffaloes. Sri Lanka.
2. The development of Foot and Mouth Disease diagnostic methods. Thailand.
3. The self-medication of ruminants in tethered husbandry systems. India.
4. The control of tick-borne diseases of ruminants in Sri Lanka.
5. The establishment of improved methods for the diagnosis and control of livestock diseases in Southeast Asia using the enzyme-linked immunosorbent assay (ELISA). Indonesia.
6. The epidemiology of Ephemeral Fever of buffaloes in China.

The projects can be arranged on a farming systems basis along the following lines, with discipline projects integrated with systems projects to test the value of results and to get necessary feedback.



A description of the methodologies and analyses of the results of some of the projects will be topics at this workshop.

This workshop has an important role to play in identifying the progress made since the first international workshop in Townsville in 1985, and establishing what are the current research priorities that need to be considered by national research teams in the region. ACIAR will welcome guidance as to what participants perceive as the research areas that Australian/Asian collaborative research groups can address with some hope of success and impact.

Issues for Consideration

— What are the likely requirements for draught animal power until the year 2000? And beyond?
— What should be the balance between disciplines such as nutrition, health, reproduction and socioeconomic research?
— How best are the results transferred and applied for the benefit of the rural communities of Asia and elsewhere in the developing world?
— Where should the emphasis be placed on Draught Animal Power research? On the animal, the harness, the implement or the system?
— Is there sufficient institutional infrastructure and training for Draught Animal Power research?
— What has been the impact of Draught Animal Power research in Asia?

The ACIAR Draught Animal Power Project

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Abstract

The ACIAR-funded project on draught animal power includes a program of collaborative research on DAP, and a commitment to communicate with other organisations involved in DAP research throughout the world. In its first Phase, the two main thrusts of research were to improve the understanding of the role of draught animals in important farming systems, and the nutrition/physiology of working animals.

Research was conducted at nine village sites in Indonesia (from Sumatera in the west, to Timor in the east), and under more controlled conditions, at the Research Institute for Animal Production in Bogor, and James Cook University and CSIRO in Townsville. Economics research was conducted by the University of Melbourne and the Centre for Agro-Economic Research in Bogor, mainly on rice farming/DAP systems in Java.

In the first 3 years, our understanding in both areas of investigation has improved markedly. Research in villages is now at the stage where several ideas for improvement of DAP systems are being tested on farms. These trials include adaptations of implements and other DAP technology, as well as trials of forages and methods of feed preservation, aimed to reduce the labour involved in rearing animals. The objectives are to develop improvements which will result in increased benefits to farmers from their DAP enterprises, and enable more farmers to rear draught animals.

The importance of DAP to rearers and to other farmers and to crop production in most Indonesian farming systems has been established. Research indicates that there is wide scope for increasing the role of draught animals in the future, especially in some farming systems, e.g. areas where animals are common but DAP implements are little used, transmigration areas and areas where land ownership is low, or where land is steep or stony and/or infrastructure is poor.

The improvement of systems will require innovative research on farms and research stations, designed to improve efficiency in DAP use and, in some systems, to reduce the need for tillage in cropping.

Introduction

THE Draught Animal Power (DAP) Project is a multidisciplinary study of draught animal systems in Southeast Asia, designed to identify ways of increasing farmer benefits from draught animal enterprises. The project is operating mainly in Indonesia, with supporting research in Australia and the involvement of the institutions shown in Fig. 1. Phase I of the project began in April 1986 and ended in July 1989.

Approach to Research

Although some researchers have attempted to provide a broad picture of the role of draught

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animals (DAs) in certain regions (e.g. Rollinson and Nell 1973; Hutasoit 1978; Falvey 1979; Petheram et al. 1985), the management and performance of DAs in farming systems have seldom been described adequately to permit the formulation of realistic plans to improve their contribution to farmer income and welfare.

In adopting a farming systems approach to research, we recognised that there is very wide variation in DAP utilisation across the regions, e.g. in Indonesia, from some eastern islands (Nusa Tenggara) where large numbers of animals are kept but are rarely used for draught, to transmigration areas where every adult animal contributes critically to work and the welfare of farming families. In addition, there is diversity in the type of work (e.g. tillage and cartage) and in the breeds of animals used (e.g. Ongole and Bali cattle, Swamp and Riverine buffalo and horses). In Java, the period of animal work varies from 10–20 days to over 200 days/year, depending on the farming system, DA density, rental markets and other factors (Fig. 2).

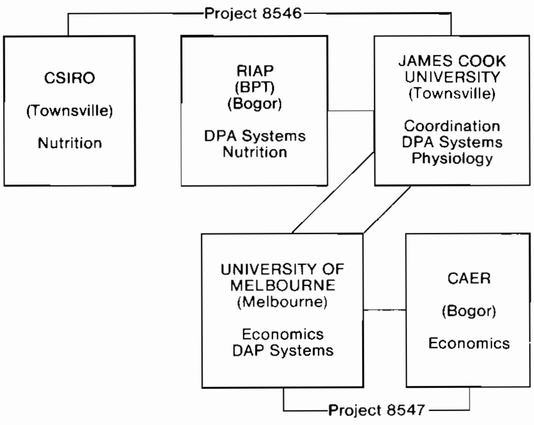

Fig. 1. Organisational structure of the ACIAR DAP Project: ACIAR — Australian Centre for International Agricultural Research; BPT — Balai Penelitian Ternak, Indonesia (or RIAP); CAER — Centre for Agro-Economic Research, Indonesia; CSIRO — Commonwealth Scientific and Industrial Research Organisation; RIAP — Research Institute for Animal Production, Indonesia (BPT).

The three main areas of research activity were:

(1) improving the understanding of the role (economic, social and biological) and management of DAP in important farming systems;

(2) improving the understanding of the nutrition and physiology of the main species and breeds of working animals; and

(3) designing and testing possible improvements to DAP systems on farms and research stations.

In addition, we actively sought to communicate with other organisations involved in DAP research and development throughout the world.

The Farming Systems Research (FSR) was conducted at selected sites in Indonesia, while nutrition/physiology research was carried out mainly at James Cook University and CSIRO in Townsville and at the Research Institute for Animal Production near Bogor (Fig. 1). Economists worked both at the village FSR sites in Indonesia, and on modelling at the University of Melbourne. Specialists in nutrition and in other disciplines became increasingly involved with FSR scientists in the diagnosis and farm testing at village sites.

The detailed studies of animal physiology on research stations was related as closely as possible to important farming systems in Indonesia, by using the same animal species and similar feedstuffs, conditions and work rates, as defined in those systems by the FSR studies.

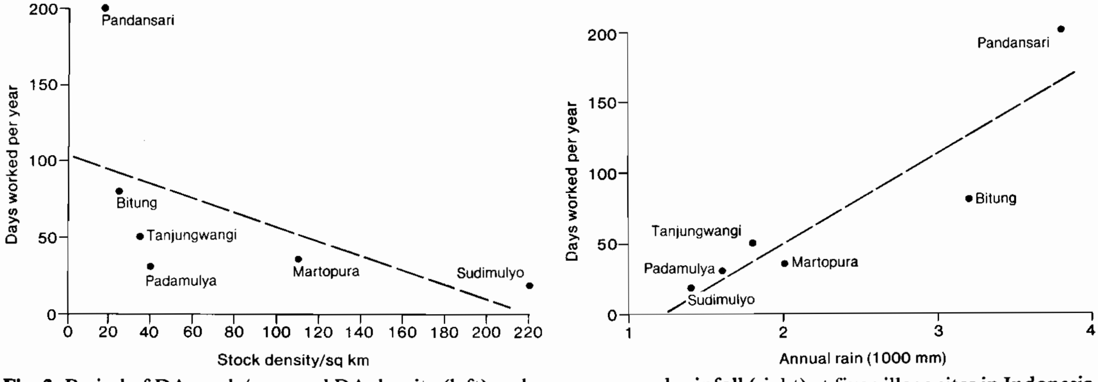

Fig. 2. Period of DA work/year and DA density (left) and average annual rainfall (right) at five village sites in Indonesia.

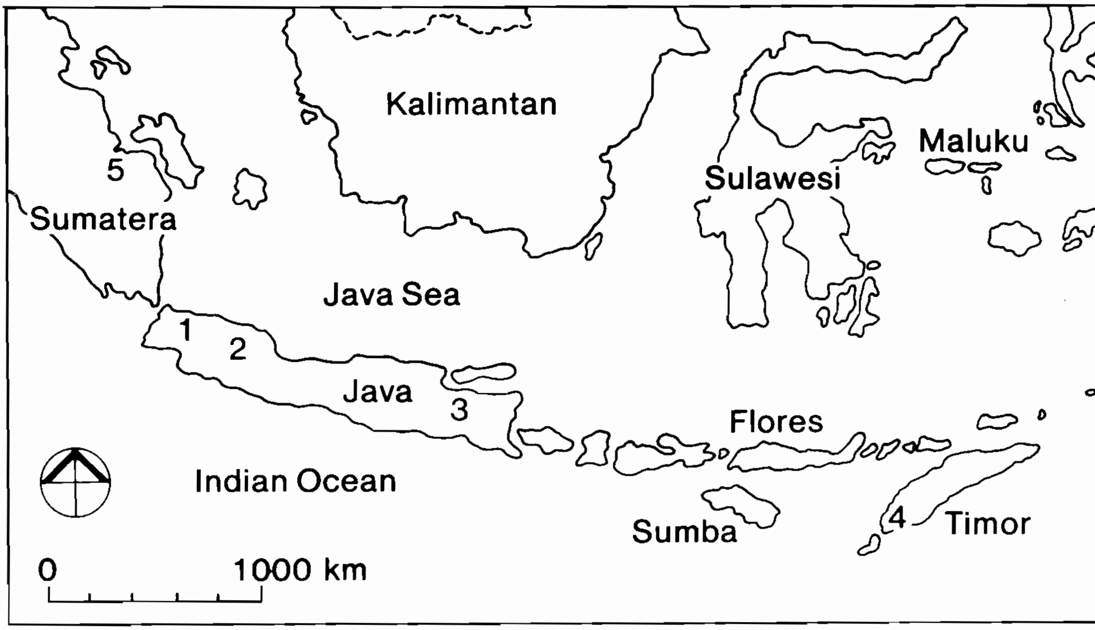

Fig. 3. Map of DAP Project research locations in Indonesia: 1. Bogor (BPT Institute and Pandansari village site), W.Java; 2. Subang village sites, W.Java; 3. Grati (BPT field centre and 2 village sites), E.Java; 4. Kupang (BPT field centre and 3 village sites, W.Timor; 5. Bitung II village (transmigration) site, S.Sumatera.

Results

Farming Systems

The first stage of the FSR was to select sites in farming systems that would allow research on the most important issues in DAP utilisation in Indonesia. The procedure adopted was to seek the opinions of livestock scientists, economists and administrators on the most important factors to be considered in selecting DAP research sites. The resulting list of criteria (Santoso et al. 1987) was used as a basis for selecting districts, then subdistricts, then villages to represent farming systems reflecting the major issues in DAP use (Fig. 3).

The FSR at each of the various project research sites (Table 1) then reached a different stage. At Subang, for example, the two research villages were described, the main constraints identified (Santoso et al. 1987; Sumanto et al. 1987) and trials were conducted on several proposals for improvement to existing systems (Table 2 and Petheram et al. 1989). In East Java and West Timor, the sites were described and trials on implements, single animal use, forages and other topics are in progress. On the other hand, in South Sumatera, a description of the research site is only partially complete.

In addition to new ideas that need testing on farms, a number of other problems and opportunities for improvement were identified at the various project sites. An example is the finding that mature bulls are in extremely short supply in many West Java villages. Unless bull availability can be improved, buffalo (and some cattle) populations are likely to decline severely. The use of AI schemes (especially for buffalo) is likely to be less effective and more expensive than the establishment of 'approved bull' schemes, where farmers are paid to keep approved bulls in villages. Poor farmer knowledge of the principles of reproduction has been identified as another probable cause of poor village herd survival.

Listed in Table 2 are some examples of constraints identified in FSR on DAP systems, together with the action required, i.e. in terms of farm trials or suggestions to policymakers about interventions needed to overcome the constraints.

While responses from farmers at all sites were

Table 1. ACIAR/DAP Project farming systems research sites 1986-89, Indonesia.

Site	Altitude	Rainfall	Livestock species	Other features
Pandansari Bogor, W.Java	Medium	High	Buffalo	Irrigated rice, rental market, paired use, mainly handfed.
Padamulya Subang, W.Java	Low	Medium	Buffalo + cattle	Rainfed rice, singles + pairs, mainly grazed.
Tanjungwangi Subang, W.Java	Medium	Medium	Buffalo + cattle	Irrigated rice, handfed + grazed.
Sudimulya Nguling, E.Java	Low	Low	Ongole cattle	Rainfed/irrigated rice, high cattle density, pairs.
Martopura Porwosari, E.Java	Medium	Medium	Ongole cattle	Irrigated rice/ soyas, wide range of implements.
Taros Kupang, W.Timor	Low	Low	Bali cattle	Irrigated rice, some DAP ploughing.
Naibonat Kupang, W.Timor	Low	Low	Bali cattle (+ buffalo)	Rainfed rice, no DAP ploughing.
Camplong W.Timor	Medium	Low	Bali cattle	Rainfed maize, rice, beans, cassava. Weeding problem.
Bitung II S. Sumatera	Low	High	Bali + local cattle	Soya beans (3x per year). Transmigration area. Strong rental market.

promising, the process of gaining farmer confidence and participation in research is extremely time-consuming and requires a strong commitment from scientists. The most encouraging response to project research to date has been in West Timor, where farmers and administrators have requested far greater involvement in trials and training in DAP technology than the resources of this project have been able to provide.

After 2-3 years of developing collaborative working relationships with farmers, the stage was reached where good participation from farmers and reliable research results can be expected at all sites of farm trials, which are central to an FSR approach.

Nutrition/Physiology

The research undertaken by JCU and CSIRO in collaboration with RIAP has, as one of its specific aims, *'the improvement of the efficiency of utilisation of draught animals and feed resources.'* Under this aim, research programs were initiated to investigate aspects in the three areas listed below (Teleni 1988). Pertinent to the development of the programs were the assumptions that:

- the use of cows is the most efficient way of utilising animals for draught purposes; and that
- a limitation to the efficient utilisation of available feed resources would be the supply of nitrogen.

The nutrition/physiology research includes work on:

1. Establishment of the validity or otherwise of using published feeding standards derived for cattle (mainly *Bos taurus*) in the feeding of buffalo. Research in this area is focused on the differences in nitrogen economy between cattle and buffalo fed rice straw under conditions of work and nonwork.

2. Definition of the limits of the 'comfort zone' for buffalo used for work under various conditions. It is well known that buffalo have a poor heat-dissipating capacity and research in this area has been undertaken to:

- identify suitable indicators (particularly metabolic) of stress and work capacity; and to
- investigate methods of expanding the 'comfort zone' by relieving stress through direct cooling or through feeding strategies.

3. Investigation of the effects of work on animal

Table 2. Some constraints and ideas identified for improvement of DAP systems.

Constraints	Ideas for improvement	Action needed: Station trials	Intervention farm trials	Notify policymakers
West Java sites				
Shortages of basal feedstuffs and of labour for feeding animals at certain times.	Plant forages close to home.	—	X	
	Preserve rice straw (in wet conditions).	X	X	
	Use animals to cart straw/forage — carts, sledges, packs.	—	X	
Shortage of high quality feed for certain periods and classes of stock.	Plant improved forages.	—	X	
	Feed salt supplement.	—	X	
	Differential feeding, e.g. of cows and calves.	—	X	
Low ploughing rate/efficiency of pairs of DAs, compared to singles (and to tractors).	Improve ploughs (wider cut)	—	X	
	Increase work period of buffalo (wet sacks).	X	X	
Lack of advice/remedies for animal health problems.	Develop cheap, local remedies.	X	X	X
Lack of advice for farmers on DAP.	Develop extension manuals.	—	—	X
Lack of capital for farmers to purchase DAs.	Credit schemes for poorest families.	—	—	X
Low calving rates resulting from: a) shortage of bulls	Approved bull schemes	—	(X)	X
b) poor farmer knowledge of principles of breeding.	Farmer training	—	X	X
East Java sites				
Extreme forage shortage from Oct-Dec.	Plant forages.		X	
High demand of DAs on capital + labour of poorer families.	Use single animals for tillage.	X	X	
Timor sites				
Non adoption of DAP implements results in late ploughing of wet rice.	Replace metal ploughs with wooden types from Java.	—	X	
	Train farmers to work animals and to make ploughs.			X
High labour demand for weeding dryland crops by hand.	Develop and test simple harrows for interrow cultivation.	X	X	

production functions, which recognises that animal work:

- places a demand on the supply of nutrients; and
- may also affect overall metabolic regulation in the short and/or long term, such that it affects basal metabolism and production functions (Kartiarso et al. 1987).

Much of the research has focused on the first, and more obvious, consideration above. Experiments have been undertaken to define the effect of work on feed intake and digestion, and to identify the important nutrients for work in buffalo and cattle. Using information thus derived, we sought to develop feeding strategies that would utilise most efficiently those feed resources available locally, both on farms and in the body reserves of female buffalo and cattle.

While the results of research have not all been analysed, the following highlights have emerged:

- on poor quality feeds, buffalo do better than cattle, in that they utilise nitrogen more efficiently than cattle;
- the use of wet hessian trunk covers are more effective than traditional methods (splashing with water) in keeping working buffalo cool (Pietersen and Ffoulkes 1988);
- it appears that feed intake in working buffalo is reduced when the diet is of poor quality;
- buffalo appear to be able to maintain higher levels of rumen ammonia and greater microbial breakdown of poor quality feed than cattle (Kennedy 1987);
- it also appears that free fatty acids and glucose are the two most important energy-yielding nutrients in the working animal. Thus acetate, the more important energy-yielding nutrient in the nonworking animal, has a diminished direct role in supplying energy to the working animal;
- thin buffalo will most probably lose cyclic activity under prolonged work periods (Bamualim et al. 1987);
- it appears that a moderately fat buffalo will stop cycling if it loses about 50 kg in liveweight (Winugroho et al. 1988).

In addition to conducting experiments under controlled conditions on research stations, the nutrition section has been involved in studies on farms at village FSR sites in Subang, West Java. Attempts were made to estimate total feed intake of animals reared on a mixture of grazing and handfeeding, using a chromium marker (Zulbardi and Bamualim 1989). Trials on farms were conducted on the preservation of dry rice straw in stacks in low altitude villages, and of green rice straw (treated with urea/lime) in higher rainfall villages, to overcome the short supply of forage in the late dry season and of labour and forage in the early wet season. At East Java sites, we intend to work with farmers to design improvements to practices in feeding animals which work for over 100 days/year.

Economics

In an initial study, data from the Centre for Agro-Economic Research in Bogor were used to estimate the technical efficiency of DAP use by rice farmers in West Java villages (Esparon 1988). An analysis of East Java villages has also been conducted (Esparon and Sturgess 1989). The conclusion of the West Java study is that farmers show 'technical efficiency' in their current production of rice, i.e. within the groups studied no farmers operated at a higher plane of efficiency than other members of their group. The significant variables to rice production were *land, urea application* and *draught animal power*, i.e. farmers could increase their production by buying more land, applying more urea or using more draught animal power.

One implication of the results is that a search for 'better' practices amongst existing technologies or management practices in that area would not result in an improvement, but that the introduction of new technologies may help farmers to raise their level of efficiency in rice production.

A related economics study involved the collection of daily data by 80 farmers in two Subang villages over a period of 54 weeks (Basuno and Perkins 1989). These data were used to develop a simulation model of farms in Subang, and to derive more accurately defined frontier production functions. The model is being used to predict the economic benefits of introducing various technologies or interventions proposed by the FSR team.

During the third year of the project, various short-term economic studies were conducted, which are considered vital to both the biological and economic components (e.g. a study of the marketing of DAs in the Subang area, an inventory of livestock transactions on farms over the past 5 years, and comparative studies of traditional trampling practices versus the use of DAs with implements in West Timor).

One important finding of the economic section in Subang is that DA rearers in some areas may be handicapped (compared to nonrearers) in their ability to earn off-farm income (Perkins and Basuno

1988). This finding provides further justification for the priority given in the project to farm research aimed at reducing the labour inputs in rearing at all sites.

All economics research, from involvement in the initial selection of project research sites, to long-term farm monitoring and short-term economic studies, was conducted in close collaboration with scientists from other research sections.

Communication Activities

While the outline above concerns mainly the research activities, the project has been active in communicating with other organisations involved in DAP research and development. The *DAP Project Bulletin* (8 issues) was distributed to over 300 scientists and organisations throughout the world, and strong linkages have been established with other networks, such as ILCA in Africa, IDRC and FAO in Asia, GTZ in West Germany, and CTVM in the United Kingdom. Video films have been valuable in gaining farmer cooperation and understanding, communicating problems and research results to other scientists, and in project publicity.

Conclusions

Our understanding of draught animal utilisation, nutrition, physiology and economics has improved markedly since the start of the project. A critical stage has been reached where this understanding must be translated into realistic and practical ideas to overcome the major constraints to improvement of existing DAP systems. The need for the different disciplines to work together and to publish results in a form digestible to all sections is proving to be critical to successful collaborative research and progress. Long-term support of research in the disciplines shown to be most important for improving DAP systems is another obvious need.

Research has confirmed the vital role that DAP enterprises play in land preparation for rice and other major crops and in supplementing farmer income. The challenge to the project and to agricultural planners is to ensure that this neglected area of livestock production is provided with the level and type of research and support needed to stimulate improvement in DAP use, and to prevent the loss of valuable draught animal resources.

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Section 2

Regional Emphasis and Progress in DAP Research

Overview of Research on Draught Animals in Southeast Asia

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Abstract

This paper highlights the role of draught animals as power sources for rural agricultural systems in Southeast Asia. Past draught animal power research is reviewed under the following headings: socioeconomics, breed improvement, reproductive physiology and AI, nutrition, environmental physiology, health, and engineering. Information on draught animal power is lacking in the region, and future research needs are highlighted.

Introduction

ACCORDING to FAO (1986) data, the populations of buffalo and cattle in Southeast Asia are approximately 19 and 28 million head respectively, and their densities in Southeast Asian countries are shown in Table 1. Most are used for draught, although mechanisation is increasing in some areas. The major role of buffalo and cattle is in tillage for rice production, i.e., ploughing and harrowing paddy fields, transporting and threshing rice. Generally, cattle are used more in dryland or upland cultivation and buffalo for muddy or lowland cultivation (Chantalakhana 1975). Most animals are traditionally employed in pairs (Konanta et al. 1985; Bamualim et al. 1988), although single animals are used in some areas (e.g. West Java and Sumatra). The other common use of draught animals (DAs) by rural people is for road transportation. In North Sumatra, Indonesia, buffalo are used for treading lime for brick making (Toelihere 1989). In Malaysia, the utilisation of buffaloes in oil palm estates is increasing, whereas it is declining in the paddy fields due to mechanisation (Kehoe and Chu 1987). The use of buffalo for hauling oil palm fruits to collection points is more economical than manual carrying and has an advantage over machines on the rough terrain (Chin 1982). Buffalo are also used for other activities (e.g. turning sugarcane crushers or pumping water in some areas of Thailand — Bunyavejchewin et al. 1985a), and harvesting bamboo, rattan and softwoods in Malaysia (Kehoe and Chu 1987).

While the vital role of DAs is recognised, especially under rainfed, small-farm conditions, not much attention by scientists and policymakers is given to research and development of DAP. Some mistakenly believe that research on DAP is retrogressive. Data on DAP in Southeast Asia are scarce in all respects, and only limited research exists in a few countries, such as Indonesia, Malaysia, the Philippines and Thailand. The purpose of this paper is to present a brief overview of past research on DAP in Southeast Asia and future research needs, with special emphasis on buffalo and cattle.

Research on DAP

Research literature on DAP can be grouped into seven categories: socioeconomics, breed improvement, reproductive physiology and AI, nutrition, environmental physiology, health, and engineering systems. It is clearly evident that most studies have been concerned with animals, while two other components, people and animal-drawn

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Table 1. DA population and density in Southeast Asian countries.

Countries	Population ('000 heads)		Density (No./'000 ha)	
	Cattle	Buffalo	Cattle	Buffalo
Brunei Darus	4	12	7.6	22.7
Burma	9,981	2,196	151.7	33.4
Indonesia	6,465	2,936	35.7	16.2
Kampuchea DM	1,571	705	88.9	39.9
Laos	593	1,017	25.7	44.1
Malaysia	620	250	18.9	7.6
Philippines	1,814	2,984	60.8	100.1
Thailand	4,835	6,302	94.5	123.1
Vietnam	2,500	2,700	76.8	83.0

implements, which also contribute greatly to DAP systems, have been much less studied.

Socioeconomic Research

One of the more common mistakes in agricultural research for the improvement of small-farm production in developing countries appears to be the failure to recognise that small farmers and existing farming systems must be understood before research is planned. This prerequisite has been termed the concept of *research with a farming systems perspective.* An understanding of farmers and their available resources and ecology, socioeconomic constraints, cultural and traditional beliefs, as well as human psychology and behaviour, has to be gained before launching any DAP research in animal sciences or engineering. The importance of socioeconomic research was well recognised when a group of DAP scientists from various countries met at James Cook University, Townsville, Australia, in 1985 (Copland 1985).

In spite of the obvious importance of DAP, it is evident that very little research has been done in the past. Most work has been concerned with the general description of livestock production and husbandry on small farms in relation to crop enterprises, but there is very little information concerning draught ability, i.e. work output of animals.

In Thailand, Rufener (1971) studied cattle and buffalo production in some villages in the Northeast. De Boer (1972) analysed the bovine production in three different physiographic villages, in terms of technical and economic constraints. Prucsasri (1976) studied Thai native cattle in villages in Kamphaengsaen District, Nakorn Pathom Province, in relation to their draught ability. Buranamanas (1963) described the seasonal pattern of work of draught buffalo in different regions of Thailand. More recently, site-specific studies of livestock in Northeast Thailand, where DAs are widely used, were conducted (e.g. in Surin Province, Northeast Thailand). Rimkeeree (1984) studied buffalo draught ability for different tasks and Sornprasitti (1987) surveyed buffalo working capacity. Na Lampang et al. (1985) studied a village bovine raising system in Srisaket Province.

Similar work has been conducted in the Philippines. Results of a survey by De Guzman (1981) in five provinces of Luzon showed the pattern of feeding and management practices, physical characteristics and the use of carabao. The results of a 3-year survey (1984–86) of buffalo raising in three regions (Luzon, Visayas and Mindanao) were documented in a PCARRD publication (Ranjhan et al. 1987).

During the last 4 years, socioeconomic research has been conducted by scientists in Indonesia through a joint research program between Australian and local institutions. Most studies have been conducted on the island of Java and published in the ACIAR-supported DAP Project Bulletin. The description of agro-profiles of some villages in relation to DA rearing (Santoso et al. 1987a,b), grazing and hand-feeding pattern (Santoso and Petheram 1987), buffalo management and productivity (Bamualim et al. 1988) are available there. Moreover, estimations of production functions for rice production (Esparon 1988) in Java, and studies of methods for land preparation in Timor, in terms of time, cost and implements (Liem et al. 1988) were conducted.

Certain aspects of comparative economics of DA versus mechanisation have been reported by a few researchers such as Sinaga and Bernsten (1982), Maranan (1983) and Onchan (1983). These surveys were conducted at specific sites and sometimes did not cover all relevant factors. The economic impact of the two power sources on production, employment and income distribution was not always clear. The results showed that farmers switched between the two power sources, depending on economic changes and farm situations. In general, no difference in yield between DAP and tractor tillage has been demonstrated.

Breed Improvement

Breeding improvement of draught cattle and buffaloes has been attempted, mainly by crossbreeding. Brahman cattle have been used widely in Southeast Asia for crossbreeding with local or indigenous cattle. The crossbreds, in general, appear to be superior to the indigenous parent, due mainly to increase in size, while maintaining heat tolerance and disease resistance of the indigenous breed (Chantalakhana 1985; Sivarajasingam 1985). The growth and reproductive performances of crossbred cattle have been studied and reported in various Southeast Asian countries, but their draught performance has not been investigated. The increase in demand for good quality beef during recent years in some of these countries has also moved interest away from the use of crossbred cattle for draught purposes.

While buffaloes remain the beast of burden in Southeast Asia, different countries, such as the Philippines, Malaysia, and Thailand, have launched programs of crossbreeding local swamp buffaloes with the riverine breeds, mainly the Murrah. The draught performance of the crossbreds under village conditions, however, remains to be seen. Similarly, on-station research is still very limited. Konanta et al. (1986) reported that Thai swamp buffalo had significantly higher ploughing capability than Swamp × Murrah crossbreds, while the performance (Garillo et al. 1987) and energy expenditure (Senakas and Neric 1988) were not found to be different in the Philippines. Further research is needed in this area.

Since 1979, an on-station systematic buffalo breeding program for draught and meat has been established in Thailand, where the national breeding herd has been kept at the Surin Research and Livestock Center of the Department of Livestock Development (DLD), Surin Province. Single-sire breeding herds of one bull to 15–20 cows have been used. Seventeen groups of about 20 highly selected buffalo calves, 10 males and 10 females, each 8–12 months of age, were sent to the Lumphya Klang Research and Livestock Center of the DLD between 1981 and 1988 for performance testing under controlled conditions for 1 year. The resulting tested bulls were used both for AI and natural mating with farmers' buffaloes (Chantalakhana 1985; Konanta 1985). However, selection programs aimed primarily at improving draught have not been reported from any Southeast Asian country.

Reproductive Physiology and AI

It is not clear how the use of animals for different types of work affects reproductive efficiency. However, some field data available indicate that work affects body condition as well as preventing natural mating (Chantalakhana et al. 1979; Perera 1985). It is important to identify clearly how different kinds of work influence reproduction in draught animals, and further, how to alleviate the negative effect of work on other types of animal performance. There are many existing reproductive and AI problems in draught cattle and buffaloes under small farm conditions, such as infertility and sterility, long calving interval, detection of heat in buffalo, AI efficiency and practical estrous synchronisation methods.

Research in cattle and buffalo reproduction has been oriented mainly towards beef and dairy production. During the last two decades, with financial support from the International Atomic Energy Agency (IAEA) (Anonymous 1989), efforts have been made by scientists in some Southeast Asian countries to improve the reproductive efficiency of large ruminants through improved heat detection, estrous synchronisation, and pregnancy diagnosis (Kamonpatana 1983). The embryo transfer (ET) technique in cattle and buffalo has also been tried with some success (Chantaraprateep et al. 1989; Kamonpatana 1987), but this technique has not been found to be useful or practical at the small farm level, especially in draught animal enterprises.

The use of radioimmunoassay techniques, in particular progesterone analysis, has been shown as a useful tool for monitoring the reproductive status of buffalo (Anonymous 1989). Jainudeen (1983), Kamonpatana (1983), and Perera (1982) are among workers who have been involved in this field of research. There is still a great need for research work in reproduction and AI which is directly related to DAs. Bamualim et al. (1987) found that working decreased ovarian activity of swamp buffalo cows; however, further research is needed to confirm this.

Nutrition

Much research on nutrition of large ruminants has been carried out in Southeast Asia, in particular, on the utilisation of agricultural by-products, crop residues and agroindustrial by-products as well as the improvement of low-quality roughage. However, this has not been directly related to draught parameters. The results from on-farm feeding trials have also been reported, but scientific information on nutrition related to working animals is lacking. However, some preliminary information on nutrient requirements of draught buffalo and cattle has been documented (Ranjhan and Pathak 1979; Kearl 1982; Mathers 1983).

After the ACIAR International DAP Workshop at James Cook University, Australia, in 1985, research on nutrition of DAs has been strengthened, particularly by the joint DAP project between Australian and Indonesian institutions. Surveys on feeding practices for DAs at village level and preliminary research concerning nutrition of DAs have been done in Indonesia, while intensive experiments on nutrition and the effect of work on rumen physiology have been conducted in Australia. Reports on parts of the research have been published in the DAP Project Bulletin (Santoso and Petheram 1987; Bamualim et al. 1987; Bamualim and Ffoulkes 1988; Bakrie et al. 1988). Some research on the effects of feed supplementation and of different planes of nutrition on draught ability of buffalo as well as rumen production pattern (Konanta et al. 1986; Wachirapakorn and Wanapat 1989; Chaidet 1989) was conducted in Thailand. The estimation of energy and protein needs of draught buffalo at varying workloads had been reported (Senakas and Neric 1988) in the Philippines. Recently, through International Development Research Centre (IDRC) support, Kasetsart University (Thailand) initiated a 2-year project to examine some nutritional aspects of draught buffalo and also to carry out socioeconomic studies in villages in Northeast Thailand.

Environmental Physiology

The ability of DAs is strongly influenced by environmental conditions, especially ambient temperature and solar radiation. Some recent research findings concerning the thermoregulation of cattle and buffalo are available from a Japanese research team of the University of Tsukuba, including Shimizu et al. (1982), Chikamune and Shimizu (1983) and Chikamune et al. (1984). Their research is concerned with the pattern of physiological variables in buffalo and cattle responding to diurnal changes.

There have been few studies in Southeast Asian countries concerning physiological responses of DAs, in terms of body temperatures, respiration rate and heart or pulse rates, as observed under various working conditions (Bunyavejchewin et al. 1985a, b; De Los Santos and Momongan 1988); and in terms of haematological values (De Los Santos and Momongan 1988). In general, while working buffalo showed signs of heat stress more quickly than cattle steers, the rate of decline under the shade appeared similar, except that in wallowing buffalo rates dropped more rapidly (Bakrie et al. 1987). The same study also reveals that steers of small and large size showed different physiological responses during work. Due to the impact of heat stress on draught buffalo, some cooling techniques were suggested, in order to increase work efficiency (Pietersen and Ffoulkes 1988; De Los Santos and Momongan 1988; Shimizu 1988).

From experience, it is apparent that measurements of certain physiological parameters in working animals have been limited for various reasons. One is the limited availability and high cost of suitably portable recording equipment; another is the high risk of losing the animal if one wishes to observe the response of animals to stress at high levels of the stress variables.

Health

The health problems of large ruminants for draught purpose in rural villages have remained much the same during the last two decades. Infectious diseases, such as foot-and-mouth, and parasites, both internal and external, have been major constraints upon DAP production, in spite of the availability of health technologies such as vaccines and anthelmintics. The real problem remains the organising of effective extension and other services. The question of how to organise small farmers and to deliver effectively services such as vaccination or deworming is an important research area. Furthermore, research on effective and appropriate methods of disease and parasite prevention and eradication in tropical environments is still seriously needed.

Heavy losses in DAs often occur among calves and these are mainly caused by gastrointestinal parasites, especially nematodes. Many research projects in Thailand have studied two kinds of important nematodes, *Neoascaris vitulorum* (Toxocara) and *Strongyloides papillosus*, which severely affect cattle and buffalo calves (Yuthisri et al. 1978; Markvichitr and Satyapant 1978; Muanguai and Luengyosluechakul 1980;

Sukhapesna 1981, 1983). In Central Luzon, Philippines, Manuel and Galdones (1982) observed the prevalence of these two kinds of round worms and found that cattle were less infectious than buffalo and that the rate of infection increased with age. Sukhapesna (1981) reported that ascariasis (Toxocara) is the most important parasitic disease and caused a very high mortality rate in buffalo calves by obstruction by the ascarids of the digestive tract. The most successful method for controlling these nematodes is to use effective anthelmintics (Sukhapesna 1981). A good number of papers concerning anthelmintic activities have been published since 1978, in the annual reports of the National Buffalo Research and Development Center, Thailand.

Among adult animals, two common infectious diseases which directly affect DAs are haemorrhagic septicaemia (HS) and foot-and-mouth disease (FMD). The former is a very serious disease causing sudden death of animals, to which the buffalo is more susceptible than cattle. The latter has a much lower physical incidence and cattle are more susceptible than buffalo. Prevention of these diseases is achieved by vaccination. Research related to effective control of these diseases has received only limited interest in the past. Neramitmansook et al. (1983) found that the immunisation against HS did not decrease the occurrence of *Trypanosoma evansi* in the blood. Anwar (1982) succeeded in controlling FMD in Malaysia through the combined effect of FMD vaccine Type A and Type O.

Besides the two diseases mentioned, other diseases such as those contributing to reproductive failure and those causing high calf mortality should receive attention from researchers. Little or no research has been reported specifically on the health of working animals in Southeast Asia.

Engineering

Engineering is an important but neglected area of DAP research in Southeast Asia. Research for the improvement of yoke and harness systems and farm tools and implements, such as plough, harrow, transplanter, and water pump, could contribute significantly to the improvement of DAP efficiency and consequently to the well-being of rural small farmers. For example, Garner (1957) showed that improved harness systems could improve work efficiency of buffaloes from 50 to 70%. But during the last 20 years very little advance has occurred in the engineering research area. Basic problems, such as standardisation of DAP measurements, also remain very much unresolved.

Today most rural farmers in Southeast Asia, especially those in rainfed and marginal areas, still employ traditional harness systems. The traditional system involves a yoke, placed on the neck of the animal, and ropes to pull the implement.

During the past 20 years, some animal-drawn farm implements have been developed by research institutions both within and outside Southeast Asia. International centres, such as ICRISAT (International Crop Research Institute for the Semi-Arid Tropics), IRRI (International Rice Research Institute), or ILCA (International Livestock Centre for Africa), have promoted some research in this area with varying success. ILCA has made draught animal research one of the major areas in its 5-year plan.

Amongst Southeast Asian countries, ploughs and harrows are the most common implements used with DAs for cultivation. However, designs for animal-drawn implements for other purposes in agriculture are available, for instance, bed-forming equipment, seeder fertiliser applicator attached to a plough, tread thresher and also stationary tools (e.g. corn sheller, water pump). In Thailand, a Thai-IRRI cooperative farm machinery project in 1978 attempted to improve traditional ploughs by varying the angle and the radius of curvature of the mouldboard in order to gain more output (Rojanasaroj et al. 1981). A joint project between Kasetsart University and the Division of Agricultural Engineering to improve a traditional water pump was conducted in 1984 for use by villagers in remote areas of northern Thailand (Anonymous 1984). However, some of the implements or equipment mentioned have not been widely used by farmers. Research is needed to determine the shortcomings of these attempts at developing improved implements.

The draught ability of animals is one potentially major research area in relation to engineering aspects of DAP research. Most research has measured DAP through related parameters, for instance, speed and load, rate of ploughing, while only a few reported the real force or power of animals (Bunyavejchewin et al. 1986; Garillo et al. 1987). It is clear that research related to these aspects cannot be done by animal scientists alone, without the assistance of engineers. General methods for DAP measurement in the field appeared in several research articles (Pathak 1985; Matthews 1987;

Table 2. Number of titles on DAP in Southeast Asia collected at IBIC and AGRIS.

Countries	IBIC (1978–88)	AGRIS (on-line search, 16 March 1989)
Thailand	9	4
Philippines	5	2
Malaysia	7	1
Indonesia	5	-

Agarwal et al. 1985, etc.). Sophisticated equipment and methods for DAP measurement are available at the Centre for Tropical Veterinary Medicine, University of Edinburgh, Scotland, where a DAP training course has been organised since 1988.

The lack of standard methods employed in DAP research by scientists in different countries is a very important problem and results from different locations cannot be compared because of the many factors involved (Pathak 1985).

Available DAP Information

In an attempt to collect all research work dealing with DAP in Southeast Asia through computer search of IBIC (International Buffalo Information Center) and Thai National AGRIS Centre, it was found that DAP information is very scarce, as shown in Table 2. Research papers on DAP were available in four countries in Southeast Asia, namely, Thailand, Philippines, Malaysia and Indonesia, in very small numbers. This collection may not be complete and up to date but at least it reflects how DAP research is being neglected, and how much future research work needs to be done. Certain works may have been published in local languages and publications such as those available in China. Hence, it is important to strengthen the information network so that all research data will be available to all scientists in this field.

Future Research Needs

Prior to the ACIAR-sponsored International Workshop on DAP held at James Cook University, Queensland, Australia, in July 1985, research on DAP in Southeast Asia appeared very sparse. The workshop contributed to the awareness of the importance of DAP in developing countries and of the needs for DAP research for development, especially in a world of rising fuel and oil prices. Very useful recommendations from the ACIAR workshop for DAP research were classified into six technical aspects, including socioeconomics (Copland 1985), which deserve high priority for national and international research support. Many of those recommendations still remain to be implemented.

We have divided future research needs into four major categories:

1. Animals

Description of husbandry practices

— Assessment of farmers' problems in DAP enterprises in farming systems related to the following:
  (1) Availability and seasonal fluctuation of feeds for DA rearing on small farms
  (2) Feeding practices
  (3) Methods of castration
  (4) Health care
  (5) Use of DA
  (6) Research on techniques for training DA

— An assessment of fodder and crop residues and agricultural by-products and the times and places when they are available

Biological study

— Research on breeding and reproduction to increase the quantity and quality of DA populations in certain areas
— The effects of work on female reproduction, especially in pregnant animals
— Evaluation of nutrient requirements of DA in different physiological states in terms of energy and protein
— Study on work productivity of DA in different types of tasks and factors affecting the output
— Improvement of DAP through nutritional methods
— Evaluation of efficient techniques to reduce heat stress developed by working buffaloes
— Environmental physiological studies related to DAP

2. Farm Implements

(1) Design of implements used with DA for different purposes in cultivation
(2) Improvements of stationary implements powered by DA, for instance, water pumps, cane crushers, winnowers and corn shellers

(3) Evaluation of traditional plough as well as other traditional implements with a view to improvement to maximise output
(4) Improvement of buffalo and cattle yoke and harness systems

3. DAP Measurement

Standardisation of research methods in DAP is an important subject in order to compare research results from different locations.

4. Socioeconomic Study

(1) Assessment of the socioeconomic situation of farmers and their attitudes in utilising DA and working with DA
(2) Economic evaluation of DAP utilisation
(3) Comparative evaluation of the economics of DAP and small tractor use
(4) Study of the adoption by farmers of implements of new design
(5) Evaluation of crossbred buffaloes under small farm conditions
(6) Assessment of the impact of the use of improved DAP techniques on farm production and farmers
(7) Conducting DAP training courses for young farmers including many topics and also post-course evaluation.

Regarding the DAP system, it is also very important to recognise that DAP efficiency depends very much on the person behind the animal. For example, the determination of the length of time an animal can work in the field under the sun may depend very much on how the person and animal interact. When the person feels hot and tired, the work usually stops. Hence, it is very important to recognise that research on social and psychological factors is needed in order to understand the farmer and animal behaviour if one wishes to improve the accuracy and efficiency of DAP research.

It is also very important to reiterate here that the DAP research process should involve not only multidisciplinary scientists involving animal science, engineering, and social sciences, but also farmers, who are the target group, as well as other beneficiaries, such as farm tool traders and salespersons.

Government Policy

In spite of the recognition of DAP, most governments in Southeast Asian countries have no clear and effective set of policies concerning DAP promotion and development. Due often to lack of stability of the governments, there is always pressure to resort to policies that can produce fast and fancy impact, although these are often inappropriate for small farms (e.g. the use of mechanisation in agriculture). DAP is generally an unfamiliar concept to most high-level government administrators and policymakers. The benefits of DAP are not easily seen by farmers and planners in the short run. The long-term impact of DAP on sustainable farm production systems has to be understood and appreciated. For this reason, planners usually underline mechanisation policies and ignore DAP development. Some even criticise DAP as backward and retrograde in agricultural development. DAP has therefore received very little research and development support in Southeast Asian countries, as compared with that allocated to the development of machinery, seed, fertiliser, or insecticides, and other forms of animal production.

It is very important for national planners to gain a real understanding and appreciation of existing farming systems and the needs of farmers in their own countries. They have to be well informed about the role of DAs and the long-term ecological and socioeconomic impact of DAP in the farming system, and of DAP versus machines on sustainable agricultural production. At the present time there is still a great need for systematic and valid data on all aspects of DAP, especially its economic importance on small farms. However, in order to gain support from planners and administrators, such data must be well organised and presented by scientists.

Conclusion

In spite of the recognition of the role of DAP in sustainable food production and income generation in rural areas, very limited research and development activities have been organised by national governments in Southeast Asia. Most research activities that are going on in their institutions today are the result of individual efforts of scientists devoted to the welfare of the rural poor. It is not easy to find research support from national governments to carry out long-term DAP research since senior administrators commonly look upon DAP as a backward and unmodern approach. Most scientists and engineers abandon DAP research for fields that might provide more pay and greater scientific recognition. The absence of a critical mass of scientists who specialise in DAP and sustain DAP research activities has been one of the most important limitations to expanded research and development.

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Role of Draught Buffalo in Rural Sri Lanka

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Abstract

Prior to 1945 buffaloes were widely used in Sri Lanka for farm power. Government farm policy began to change rapidly with the introduction of tractors in 1945–46. As a result of this policy, by the end of 1987, 70% of paddy land in the Dry Zone and about 45% of the paddy land in the whole of Sri Lanka was worked with tractors. The official support for the policy in favour of the use of tractors took the form of bank credit, the concessionary availability of foreign exchange, low import duties and subsidies on fuel. There were two main reasons given for this support: mechanisation would increase food production, and tractors would modernise agriculture.

The tractor-based strategy had several disadvantages: (1) It created new social differentiations between the farmers and tractor owners, resulting in the exploitation of the farmers; (2) It displaced family labour from agricultural activities, particularly in the management of draught animals; (3) It depleted foreign exchange; (4) It resulted in higher costs of operation; and (5) It was uneconomic for smallholders.

There is now a reverse trend towards draught animals in rural Sri Lanka, particularly in new colonisation schemes in the dry and intermediate zones. Under the schemes each family is given 1 ha of paddy land and 0.2 ha of highland, and the settlers generally prefer draught animals, particularly buffaloes, to provide the necessary farm power.

As the person–land ratio becomes smaller, with smaller grazing grounds for draught animals, DAP will be limited in countries like Sri Lanka. Therefore research should be continued with greater vigour to produce supplementary animal feeds such as urea-ensiled paddy straw. It has to be noted, however, that farmers will accept new animal feeds only if available at a price which they can afford. The establishment of common grazing grounds is also a necessary prerequisite for the improvement of DAP.

Introduction

THE buffalo was first domesticated in the Indus Valley around the middle of the third millenium BC. The Sri Lankan swamp-type wild buffalo was domesticated by the first agricultural settlers who migrated from India around the 6th and 5th centuries BC. The Sri Lanka buffalo has crescent-shaped horns and there is considerable variation in skin colour, the commonest being leaden grey. It is smaller in size than other swamp buffaloes used for draught in many South and Southeast Asian countries. Evidence from the earliest periods of the irrigation civilisation in the Dry Zone of Sri Lanka[1] (600 BC to 1300 AD) as well as evidence from subsequent periods indicate that buffaloes have been used in both field preparation and threshing activities connected with paddy cultivation. Although buffaloes were also used as pack animals, for drawing carts and as the source of power for oil extracting and water-lifting equipment, oxen were preferred (Siriweera 1982).

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[1] Sri Lanka is divided into three broad climatic zones, the Wet Zone (1.52 million ha), the Dry Zone (4.12 million ha) and the Intermediate Zone (0.84 million ha). The mean annual rainfall on which the above classification is based varies from 2280 to 5100 mm in the Wet Zone, 1525 to 2280 mm in the Intermediate Zone and 890 to 1525 mm in the Dry Zone.

Farm Power Policy: the Shift Towards Mechanisation

The farm power policy in Sri Lanka began to change rapidly with the introduction of tractors in 1945–46, initially by utilising approximately 150 four-wheel tractors left behind by the British military authorities after the Second World War. Politicians and administrators took the position that four-wheel tractors would contribute towards the expansion of cultivated area, more timely ploughing, saving in irrigation water through reduced staggering of cultivation and a reduction in peak season labour bottlenecks in the newly settled Dry Zone areas. As they further pressed for mechanisation, 500 four-wheel tractors were imported from Britain in the early 1950s. A gift of 175 four-wheel tractors from Australia supplemented the stock in 1953. By the end of 1988 the annual paddy acreage ploughed by tractors had increased to 10% in the Wet Zone, 30% in the Intermediate Zone and 70% in the Dry Zone. About 45% of the total paddy land in Sri Lanka is ploughed by tractors with the remainder distributed between buffaloes, a few cattle and mammoty tillage (Ryan et al. 1981). The percentage of tractors used in threshing is even higher.

During the last 40 years there has been a strong bias in official policy towards the use of tractors in paddy cultivation. Official support has taken the form of subsidies on fuel, bank credit and concessionary provision of foreign exchange. Tractorisation has been viewed by politicians and planners as a means of increasing food production and is also associated with modernity and efficiency. The official policy remains strongly in favour of the expansion of tractor use as evident from the increasing number of tractor imports (Farrington and Abeyratna 1982). In 1973 there were 1311 registered 2-wheel tractors and 12 171 4-wheel tractors, and in 1980 the figures were 13 325 and 21 375 respectively.

While tractorisation took place at the expense of animal draught, there has been no definite policy regarding the improvement of animal farm power, both cattle and buffaloes. Government activities have centred largely on salvaging draught stock by prohibiting the slaughter of buffaloes for meat. According to official figures only 29 buffaloes were slaughtered in 1978, 7 in 1979 and none thereafter. These figures are unrealistic and government policy in saving buffalo stock has not been very effective. According to contradictory official statistics, the government-owned Ceylon Leather Products Corporation processed 2580 and 4000 buffalo hides in 1978 and 1979 respectively. The actual national rate of slaughter may be in excess of 30 000/annum.

Disadvantages of Tractorisation

It has to be stressed that the tractor-based strategy in farming has several disadvantages, particularly in the Third World, as evident from the experiences of Sri Lanka. The concentration of wealth in the hands of a few entrepreneurs from within and outside the settlements due to tractorisation has created new social divisions among the poorer people and new forms of exploitation. In certain instances, where equal areas of land are allocated to settlers in colonisation schemes, tractor owners from within these schemes have acquired rights over more land through illegal and informal transactions: some settlers in colonisation schemes have become tenants of their own lands. The social and economic relations arising from these circumstances result in the increasing exploitation of the larger segment of the community by a small group of entrepreneurs.

Encouragement of mechanised farm power in village economies has resulted in the displacement of family labour from agricultural activities and in the discouragement of the maintenance of herds (Farrington and Abeyratna 1982). It may be worth noting here that both children and old people are engaged in maintenance of herds — their labour may be of low value in other agricultural activity. For old people, looking after the animals is also a form of recreation. The infrastructure available for nonagricultural enterprises in village economies is marginal, and displacement of family labour will ultimately result in the creation of an underemployed work force. Tractors do generate employment in the transport, maintenance and operations sectors but such employment is slight when compared with the displacement of labour by machines.

It should also be emphasised that the use of tractors in paddy land tillage systems practiced in the Dry Zone of Sri Lanka — where regulated irrigation systems exist — has not contributed to an improvement in the synchronisation of field preparation with irrigation schedules. In addition, the government policy of promoting tractorisation through providing low import duties, subsidised credit and subsidised foreign exchange for tractor imports has been a burden on the public purse, and has contributed only marginally to the national economy above the achievements that could have been made with indigenous draught power resources (Farrington and Abeyratna 1982).

A comparison of the operating costs of tractors and buffaloes also provides strong economic justification for expanding the role of animal power in cultivation. Tractor owners have been the market leaders in fixing charges by transferring costs of maintenance and fuel to the farmer without any reduction in their profit margins. The 4-wheel tractor hire charge for land preparation was Rupees[2] 254/ha in 1972, 960/ha in 1979–80 and increased to 3264/ha in 1986–87. The charges for buffaloes have also increased correspondingly from Rs 120/ha in 1972 to Rs 480/ha in 1979–80 and to Rs 2232/ha in 1986–87. The figures in Table 1 demonstrate that draught animal power is still cheaper than mechanised draught power.

With continued increases in world market fuel prices and the capital cost of imported tractors and implements, the cost disparities between animal and mechanical draught can be expected to widen.

Tractors have a clear advantage over traditional draught systems only in the cultivation of large areas of rainfed or irrigated land rather than in small paddy holdings. As shown in Table 2, most paddy landholders could benefit from animal draught in paddy cultivation rather than from tractors.

Table 1. Average costs of different modes of farm power in field preparation 1986–87 (rupees/ha).

Mode	Owners	Hirers
4-wheel tractor	10621	3359
2-wheel tractor	766	2828
Buffalo	815	2297
Cattle	531	2297

Table 2. Number, acreage and size of paddy holdings.

Size (ha)	No. of holdings	%	Area (ha)	%
<0.4	319,950	43.5	57,718	11.8
0.4–0.8	174,558	23.8	85,092	17.3
0.8–1.2	114,325	15.7	101,478	20.7
1.2–2.8	109,177	14.8	166,743	34.0
2.8–4.0	7,635	1.0	24,310	4.9
>4.0	8,887	1.2	55,591	11.3

Source: Census of Agriculture 1982.

[2] Sri Lanka has a floating currency rate which has varied from time to time. In April 1989 approximately 34 rupees was equivalent to 1 US$. Hereafter, in most places rupees will be referred to by the abbreviation Rs.

Upgrading of Draught Animals

Rising costs of mechanisation and other inputs have made cultivation of small paddy holdings in Sri Lanka uneconomic. Consequently a trend towards animal draught is discernible in the rural sector. However, current breeding efforts to upgrade local stock for increased draught power are inadequate. There are 42 Livestock Farms under the Department of Animal Production and Health and the National Livestock Development Board, in addition to six farms established by the Mahaweli Authority, the organisation repsonsible for settlement under the largest river diversion irrigation project in the country. In these farms, greater attention has been paid to upgrading cattle by cross-breeding them with Tharparkar and Sahiwal animals imported from Pakistan. There is a high demand among the farmers for these upgraded animals for both cultivation and dairy purposes. One of these upgrading programs of the Mahaweli Authority is called the 'Board and Lodging Program.' Within this program, settlers can take their cattle and breedable heifers for pregnancy diagnosis. Animals found to be pregnant are taken away by their owners while those which are cycling normally are moved to a special area on the farm. Over the next 30 days these cows are mated to Sahiwal and Tharparkar sires. By this means an accelerated upgrading is envisaged and the program expects the replacement of indigenous stock by 50% crosses. The draught power potential and milk yield from the crossbred animal were higher than that of the indigenous animal.

But in all farms the upgrading of draught buffaloes occupies a secondary place, first place being given to dairy development of cattle breeds. In these farms some attention has also been paid to imported Indian buffalo breeds such as *Surti* and *Murrah*, and the Pakistani breed of *Nili-Ravi* and their crosses for increasing milk yields and for draught purposes.

Ownership and Utilisation Patterns

There is a significant discrepancy in the data available that relates to the buffalo population in Sri Lanka and its rate of change. The Census of Agriculture gives the total number as 562 297 in 1982 and the Annual Livestock Population Survey prepared by the Department of Census and Statistics estimates the buffalo population in 1982 at 879 000. Individual field research done in some districts compares fairly well with the population estimated by the Annual Livestock Population Survey.

However, the only statement concerning buffalo stocks that can be made with confidence is that until the quality of the statistical base is improved, the success of many planning decisions on buffalo promotion and tillage requirements will be jeopardised.

On the other hand, the data on the ownership pattern of buffaloes in Sri Lanka is reliable and indicates an uneven pattern. For instance, in the Uda Walawe area, there is an average of 40 adult buffaloes/owner as against 13 at Padaviya, 3 at Kaudulla, 4 at Minneriya, and 3-4 at Kurunegala (Farrington and Abeyratna 1982). But generally, in many parts of the Dry Zone, the size of the average herd of draught animals is large and the number of the owners comparatively small. This ownership pattern is accompanied by low levels of husbandry and low-use levels, factors not conducive to high land use intensities implicit in the current large-scale development of major irrigation.

Of the total number of buffaloes in Sri Lanka only about 40%, including a small number of buffalo cows, are used for cultivation purposes. Therefore the buffalo as a source of farm power appears to be greatly underutilised, and varies from region to region. In general, buffaloes can be used in four important stages of paddy cultivation: ploughing, puddling, levelling and threshing. These vary according to soil conditions, the size of the *liyaddas* or small-bunded paddy plots in a field, the geographical location of the paddy field, its accessibility by tractors and the type of farm power available. Buffaloes are generally tied abreast in pairs for ploughing and levelling and in groups of 2, 4, 6 or 8 for puddling and threshing. The puddling or threshing unit is called *kerella* and one or more *kerellas* are put into the inundated field or threshing area each driven by a single person. In some regions buffaloes are used for all four key stages of paddy cultivation but sometimes certain stages are omitted. It should be noted that some ploughing methods using animal draught involve an element of puddling and levelling which reduces the time spent on these operations later. In certain instances they are used for the first three stages of cultivation, but in threshing they are replaced by tractors. There are still some other regions where tractors are used for initial ploughing and threshing, and buffaloes are used for puddling and levelling. Buffalo puddling is effective in eradicating weeds and in helping to crush the remnants of roots and stumps of trees in the soil. Comparatively larger hooves, more flexible pastern and fetlock joints, better ability to work in deep mud and the slower ponderous gait of the buffaloes give buffaloes an advantage over cattle or tractors in the type of work associated with paddy farming.

The utilisation of buffaloes for purposes other than farming, such as for milking, is not uniform in Sri Lanka. In Hambantota, Batticaloa and Polonnaruwa districts they are used for dairy purposes and to a lesser extent in Trincomalee, Matara, Kalutara and Ratnapura districts, but not in other areas. These differences appear to be purely a matter of tradition. The milk is largely used for making curd and ghee, which is the cooking oil favoured by Hindus and Muslims. But on the whole, only about 13% of the country's buffalo population is used for milking. This underutilisation of buffaloes for dairy purposes is largely due to the low yields of swamp-type buffaloes in Sri Lanka, which have not undergone selective breeding for milk production. The average mean lactation yield of the Sri Lanka buffalo is around 1.5 l/day, and lactation lasts for about 3-6 months. Due to its low production the indigenous buffalo is milked only once a day. On the other hand the imported *Murrah* buffalo yields about 4-6 l/day. The use of buffaloes for milk in Sri Lanka is in sharp contrast to that in India and Pakistan, where the largest number of river buffaloes are found, and about 70% of the milk consumed is obtained from these types. Buffalo dung, like cattle dung, is used as a fertiliser for crops, for application on the floor of rural dwelling houses and for the production of biogas. Although the use of these animals for clay mixing prior to baking bricks is prevalent in a few areas of the country, they are no longer used for other work such as to power oil extraction, to operate water-lifting equipment or for road haulage, as was done in the past.

Management and Feeding Patterns

The management and feeding patterns of the Sri Lankan buffalo also vary slightly from place to place. In traditional villages in the Dry and Intermediate zones, buffaloes are driven to the jungle, if available, for grazing. Where jungle land is not available, they are grazed on scrub lands, common grazing lands and tank beds. After the harvest they are allowed to feed on the stubble of paddy fields. In such cases they are paddocked for the night. In the Wet Zone, and in some of the Dry Zone colonisation schemes, buffaloes are tethered in home gardens and are fed with cut grass. Grazing, tending and tethering are shared by adults and children alike, both male and female. Hired labour is almost nonexistent as far as the rearing of animals is concerned, except on government farms.

An interesting aspect of both buffalo and cattle husbandry practices in Sri Lanka is the *ande* system. Some of the herd owners resort to this *ande* system as an easy way of maintaining animals and the nonowners make use of the system in order to own a few animals. Rearing, tending, health management, etc., are the responsibility of the person who looks after the animals in the *ande* system. When calves are born, ownership of the first calf goes to the owner of the cow and the second calf to the person who looks after the stock. If excess calves are sold the proceeds are shared between the owner and the *ande* holder. If buffaloes and cattle are given on hire by the *ande* holder, the income accrues to that person. According to the *ande* arrangements financial benefits accruing from the sale of milk also go to the *ande* holder. The main benefits derived by the owner are that the *ande* holder is bound to supply milk for the owner's domestic consumption and also to provide the animals for the owner's cultivation requirements along with the *ande* holder's labour.

No supplementary feed in the form of fodder or concentrates is provided to buffaloes except in very rare instances and that too in areas where there is an acute shortage of grazing lands. However, since 1981, with the collaboration of the Ministry for Development of Cooperation of the Netherlands, Sri Lanka has started a Straw Treatment Project with the objective of improving the nutritive value of paddy straw as cattle feed (Perdok 1982). As a result urea-ensiled paddy straw has also been introduced as feed in recent times on an experimental basis in some government farms. Straw treatment, if successful, will be a major technological innovation using small amounts of scarce resources in conjunction with large amounts of plentiful ones. It could also have a significant effect on buffaloes and cattle in Sri Lanka as in all developing countries, as better feeding could enhance the draught power potential of the animals. However, if urea-ensiled paddy straw is to be acceptable to farmers as cattle feed then urea will need to be made available at an affordable price.

Both indigenous and western treatment methods are practiced in treating diseases of animals; in remote rural areas the latter is more prevalent. It is interesting to note that, in addition to actual treatment, religious and superstitious beliefs also play an important role in the indigenous healing system. Praying to gods in front of the sick animal, branding various formulae on the animal's skin, chanting *mantras* or incantations and offerings to God are common features in this traditional healing system. But on the whole, in urban as well as rural society the efficacy of the western treatment has generally been accepted.

Buffalo Rearing and New Trends in DAP

Although vaccination programs and veterinary facilities have been considerably expanded in recent years, planners and policymakers have neglected one of the key areas of rearing draught animals, particularly buffaloes. At present the biggest problem faced by the farmers in many regions, particularly during dry seasons, is the shortage of grazing grounds and wallowing facilities for buffaloes. The problems are well illustrated in a recent field study done in the Mahaweli settlement area called 'System C' (Siriweera et al. 1987–88). System C is an area where there was a sparse population and relatively large herds of buffaloes and cattle. The buffalo was the norm in the paddy sector in the region. From 1980 onwards three categories of settlers were accommodated in the region: (1) those original settlers in the region before the Mahaweli Development Program started; (2) those who were displaced in other areas as a result of major construction work related to the Mahaweli Project; and (3) those who were selected for allocation of land from the areas of high population density. Each family was given 1 ha of paddy and one-fifth of a hectare of upland and, by the end of 1986, 12 600 families had been settled in System C. Their income levels and assets were not uniform. Over 23% of families received incomes of less than Rs 12 000/year and 71% received incomes between Rs 12 000 and 24 000. The very nature of agricultural life and the essentially cyclical nature of the production process have placed more than 90% of households in a position of indebtedness to individuals as well as lending institutions. The age distribution showed the settler population to be relatively young; up to 81% of the population is below 40 years, which is well above the average for Sri Lanka. The average size of over 75% of the families was six or less.

The government did not interfere with the choice of the settlers with regard to farm power. However, the study showed that planners had neglected needs

Table 3. Pattern of buffalo and cattle ownership Mahaweli System C — 1986-87 (696 households surveyed).

Size of herd	Households owning Buffalo	Cattle
0	560	290
0–2	45	182
3–5	43	121
6–8	14	60
9–15	22	28
16–22	5	4
23–29	2	3
30 and over	5	8

Table 4. Pattern of farm power utilisation in field preparation in Mahaweli System C — 1986-87, Maha/Yala.

	Plough I	Plough II	Puddling	Levelling
	%	%	%	%
Cattle	64	57	10	46
Buffalo	12	10	20	10
Cattle/Buffalo	15	15	9	9
2-wheel tractor	6	6	1	4
4-wheel tractor	3	2	–	–
Manual	–	–	–	31
No operations	–	10	60	–

for grazing and wallowing for animals in the area. As a result the original settler category, some of whom owned large herds of buffalo, have sold most of their animals for illegal slaughter. It was also noted that all except one who presently own more than 30 buffaloes are original pre-Mahaweli settlers. More than 80% of families in 1986-87 did not own buffalo, but around 60% owned some cattle (Table 3).

As wallowing and grazing facilities are limited in this area there is a tendency for buffalo owners to drive their animals to irrigation canals and small reservoirs, resulting in damage to irrigation works. Problems of limited grazing also have contributed to crop damage by buffaloes and cattle. The farmers also believe that buffaloes are more prone to escape from the area where they are kept and cause greater damage to crops than cattle.

It was further observed in the study that buffalo are less productive than cattle during the dry season. There are instances where buffalo are paired with cattle for ploughing. In such cases the buffalo require rest during midday and work only for about 5 hours/day, whereas cattle could continue to work for about 8 hours without prolonged rest. Farmers have responded to these circumstances by substituting buffalo with cattle as draught power. The farmer's choice and the use pattern of draught power in the study locations are shown in Table 4.

Farmers find that even where facilities for open grazing are not available small herds of cattle could be reared in their homesteads under stall-feeding, and also that intensive feeding is not unprofitable because of the greater utility of cattle as compared with buffalo.

Nevertheless, it should be noted that in areas where soils are boggy and prone to flooding neither tractors nor cattle could operate as efficiently as buffalo in field preparation. The depth as well as the fine texture of soil undoubtedly make the buffalo the most effective mode of farm power in such regions, as is evident in most of the Wet Zone regions of Sri Lanka.

Conclusion

Sustenance and improvement of animal draught power is imperative for Sri Lankan agriculture. With major land development programs the demand for draught power is increasing at a time when adverse terms of trade and balance of payments deficits make it difficult to support the tractor-based strategy. The escalating costs of tractors, spare parts and fuel and the differences between tractor and animal draught costs provide strong arguments for expanding the role of animal power. Apart from high monetary costs and operational difficulties faced by the farmers, social costs such as concentration of wealth in the hands of a few and the displacement of family labour are some of the other problems associated with tractors and particularly four-wheeled tractors.

While stressing the importance of animal draught and the inappropriateness of foreign technologies, such as tractors, it may be observed that in farming, where the relationships between land, human labour, animal draught and water resources are not very flexible, it is unrealistic to think of a single mode of draught power. At present, three major levels of technology are available for agricultural operations — hand tool technology, animal draught technology and mechanical power technology. Each level has different degrees of sophistication. Each level and degree has different technical, economic and social implications and consequences. Draught power and mechanisation issues are complex and their impact depends on the type of technology selected for a specific situation in a particular region or locality. However, especially in Third World farming there is no doubt that, apart from the systematic promotion of animal draught, simple and inexpensive hand tool technologies should also be improved.

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Research on Draught Animal Power in India

N.S.L. Srivastava*

Abstract

The use of draught animals in agriculture for crop production and rural transport is very important in India, and will continue to be for many more years. In spite of the rapid increase in the number of tractors during the last 15 years, about 90% of the tillage and sowing operations, and about 70% of rural transport, are still being done using the 85 million draught animals in India. With the expansion and availability of electricity and road systems in villages, the use of draught animals is decreasing. On the other hand, increased intensity of cropping demands increased energy input in agriculture, which puts pressure on other sources of energy like petroleum oil and lubricants, electricity, coal, etc., which are becoming scarcer and costlier. Therefore efforts are under way to increase the use and overall efficiency of draught animals to reduce pressure on other sources of energy. This paper reports on this research effort.

Introduction

DRAUGHT animals provide an important source of power in agriculture in India, and will continue to fulfil this vital role for many more decades. Most of the farmers in India follow mixed farming practices, often including horticulture, dairying, goats, poultry, pigs, fish, etc. Draught animals therefore fit in very well in their whole system.

On Indian farms, power is available from humans, draught animals, tractors, power tillers, diesel engines, and electric motors (136 million hp in 1984 from all sources; draught animals contributed about 31%). For crop production operations, barring irrigation and to some extent threshing, the main sources of power availability are human, draught animals, tractors and power tillers. Power availability from these four sources in major states of the country in 1984 ranged from 0.35 hp/ha to 1.65 hp/ha, with an average of 0.56 hp/ha. The 85 million draught animals contributed about 54%. In terms of actual work output, however, especially for tillage and sowing operations, it was about 90% since 1 hp/hour of animal energy can produce work equivalent to about 6–7 hp/hour of tractor energy (Table 1).

Presently a pair of animals, on average, can work about 2–3 ha. It has been demonstrated that with proper management, care and use of improved matching implements a pair of animals can work 4–6 ha, thereby minimising the requirement of additional power from other sources.

Draught Ability of Animals

The draught power of an animal depends on the species, breed, sex, size, body weight, nutrition and health, environment, training for work and terrain conditions. Several studies have been conducted on the draught ability of animals during different seasons. Using local yokes/harnesses and in sustained working conditions of 6–8 hours, different animals performed as follows:

Animal	Draught equivalent to % of body weight: Summer %	Winter %	Duration of work (hours)
Bullocks	12	14	7
Male buffaloes	10	12	6
Camels	15	16	7
Donkeys	32	34	6

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Table 1. Energy required for seedbed preparation and sowing operations for soybean crop in black soil using animal and tractor power.

Operations	Energy required to cover 1 ha			
	Using a pair of bullocks		Using 35-hp tractor	
	Time (hours)	hp/hour	Time (hours)	hp/hour
1. Ploughing (once)	40	40	5.00	175.00
2. Harrowing (twice)	16	16	5.00	175.00
3. Seed drilling (40 cm row spacing)	5[a]	5	1.75[b]	61.25

[a] 3-row drill.
[b] 5-row drill.

For shorter durations (30 min to 2 hours) bullocks and male buffaloes can exert draught up to 15–25% of their body weight. Camels can exert up to 22% and donkeys 36%. At higher draught loads the speed of animals slowed down. Maximum power and work output were obtained at slightly lower values of draught loads than the maximum load they could exert under sustained working.

Studies conducted at CIAE Bhopal and elsewhere on crossbred humpless bullocks have shown that they are also good for draught purposes. They can exert up to 12–14% of their body weight in sustained working, and even higher for shorter durations. Crossbred bullocks get exhausted quickly in hot weather conditions, and it is advisable to use them during morning and evening hours.

To increase draught availability from animals, research efforts are being made in three directions.

(1) Developing Improved Yokes and Harnesses

The draught force from the animals to the implement is transmitted through neck muscles with the help of a yoke. The amount of force which the animal can exert will depend on how comfortable the yoke is.

Improved wooden yokes and single and double animal harnesses with padded collars have been developed and field-evaluated for oxen and male buffaloes. The Nagpuri wooden yoke (Fig. 1) has given 7–15% higher power output over local yokes. This yoke has wider and better contact with the necks of animals.

CIAE and Allahabad-type single animal harnesses and Allahabad double animal harnesses for bullocks and buffaloes gave 15–25% higher power output over local yokes. Because of the padding these harnesses are comfortable for the animals.

An adjustable modified Nagpuri yoke has been developed at Pantnagar to take care of various row spacings ranging from 65 to 135 cm.

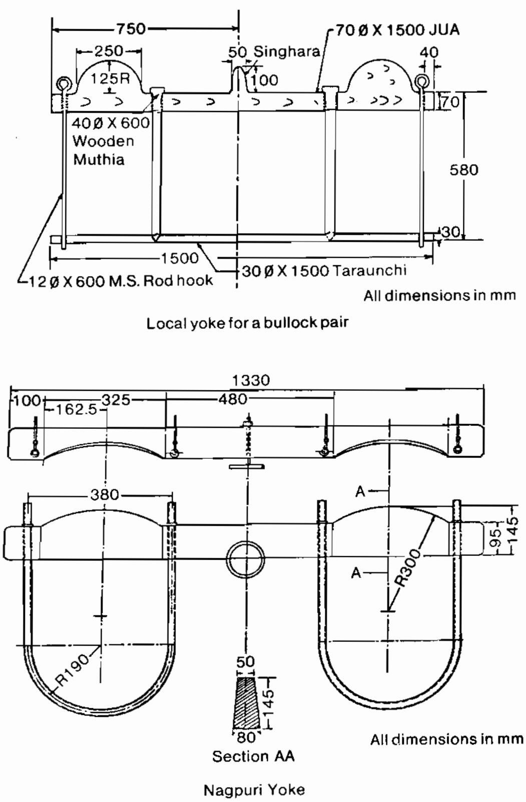

Fig. 1. Local and Nagpuri yokes.

For camels, inverted V-shaped short and long harness with and without padded collars on the neck are used. Short-length harness is kept ahead of the hump and camel back whereas longer harness covers the hump also. The contact area in short harness is about 1800 cm^2, whereas for long harness it is about

3200 cm^2. In trials both the harnesses gave similar performance.

For horses, mules and donkeys breast-type harnesses are used.

Efforts are being made to popularise padded collar type and breast-type harnesses for various types of animals.

(2) Energy Conversion

Studies on the output of draught animals have shown that their total output (energy furnished by animals and available for work divided by the energy contained in its ration) over a long working period is of the order of 0.1 to 0.12 for horses and 0.09 to 0.1 for bovines. For humans it is about 0.12.

The draught animals are normally fed on fibrous crop residues and dry grasses, with low nutritive values. During the working season draught animals require a higher nutrient supply than during slack periods. Supplementing the staple feeds with foodstuffs of higher nutritive value is desirable but not always possible. In designing feed rations for draught animals under these conditions, it is useful to be able to predict voluntary food intake with some accuracy, particularly when it is likely that it may limit production.

In some studies addition of urea (1.2%) in alkali-treated straw resulted in 50 and 63% increases in voluntary food intake by buffaloes and bullocks, respectively. Water intake also increased in a similar way. Higher food intake will result in higher output.

Studies have been initiated on nutritional aspects of DAP to explore possibilities of improving feed-work output ratios.

(3) Mechanics of Animal Traction

Studies conducted on the mechanics of animal traction have revealed that in harnessing of draught animals or designing animal-drawn implements, the following points should be kept in mind.

(i) As far as possible the line of pull should pass through the centre of gravity of the animal.

(ii) Small-diameter wheels or low height of implements having a lower centre of gravity are more suitable for steep slopes.

(iii) Three-pad collar harness is superior to single-point neck harness in all situations, as the animals will not be unduly strained due to the shift of the line of pull from the centre of gravity of the animal while going up or down hill. This condition will hold good even for larger-diameter wheels or higher implements.

(iv) Wheel braking is desirable for animal carts.

(v) For sloping terrain, animals with small stature, and well-built wide body will be the most suitable.

Quantifying and Measuring Fatigue

Presently there is no standard technique for quantifying and measuring fatigue and the degree of fatigue based on visual and physiological

Table 2. Fatigue score card for draught animals.

	Score scale					Total
	1	2	3	4	5	
Respiration rate (breaths/min)	+Ro+15	Ro+30	Ro+45	Ro+60	Ro+75	5
Heart rate (beats/min)	+Ho+10	Ho+20	Ho+30	Ho+40	Ho+50	5
Rectal temperature (°C)	+To+0.5	To+1.0	To+1.5	To+2.0	To+2.5	5
Frothing	First appearance	Dribbling of saliva starting	Continuous dribbling	Appearance of froth on upper lip	Full mouth frothing	5
Leg uncoordination	Strides uneven	Occasional dragging of feet	Movements of legs unco-ordinated and frequent dragging of feet	No coordination in fore- and hind-legs	Unable to move because of uncoordination	5
Excitement	Composed	Disturbed	Nostrils dilated and bad temperament	Movement of eye wall prominent with excitement	Furious and trying to stop	5
Inhibition of progressive movement	Brisk	Free movement	Slow walking	Very slow	Stop walking	5
Tongue protrusion	Mouth closed	Occasional opening of mouth	Frequent appearance of tongue	Continuous protrusion of tongue	Tongue fully out	5

+ Ro, Ho, To represent initial respiration rate, heart rate and rectal temperature, respectively (Upadhyay and Madan 1985).

symptoms. Upadhyay (These Proceedings) has prepared a fatigue score card (Table 2) which is useful and is currently being used for studies in bullocks and buffaloes. It has not been extensively tried and verified for assessing fatigue of animals during field operations like ploughing, harrowing, puddling, etc. The score card also does not include degree of fatigue. There is no fatigue score card for camels, donkeys, mules and horses. The animal scientists mainly depend on blood analysis for lactic acid, which may be reliable but is not practicable in field studies on draught ability where frequent readings are to be taken.

Basic research has been initiated for standardising techniques for quantifying and measuring fatigue based on visual and easily measurable physiological symptoms. Both laboratory studies on treadmill under controlled environmental conditions and field studies are being conducted. Portable instrumentation is being used/developed for field measurement of physiological (heartbeat, respiration rate, body temperature, O_2 consumption, etc.), load (pull and angle of pull), speed (speed of working and stepping rate) parameters and weather conditions.

In the absence of a standard method of quantifying and measuring fatigue there is no standard method for scheduling work/rest cycles (see Maurya 1987 for a detailed rest cycle proposal).

Instrumentation for DAP Research

Loading Cars for Draught Ability Studies

Several loading cars have been developed in India for draught ability studies: i) sledge type; ii) winch type; iii) suspended weight type; and iv) hydraulic type.

Out of eight designs developed, CIAE animal loading cars of 500 kg and 300 kg (Fig. 2) draught capacities are best from the point of view of ruggedness, versatility and reliability. Both these loading cars are similar in design and are hydraulic types. In these loading cars standard jeep axle differential systems have been used. Two gear pumps in the first design and one in the second design are operated through ground wheels with suitable speed increase. The flow of the fluid from these pumps is restricted with the help of check valve and pressure relief valves putting the load or braking effect on the wheels. The maintenance of load settings is easy and reliable and is not affected by variations of speed in the range of 1.8-5 km/hour.

Dynamometers for Measuring Pull

Spring, hydraulic and load cell type dynamometers are commercially available for measuring pull. Load cells are more precise and accurate and are preferred over the other two types of dynamometers. Designs of suitable fixtures have been developed for proper mounting of these dynamometers on implements.

Measuring of Angle of Pull

For measuring angle of pull an Abney level should be used. This level is kept on the beam or rope and indicates the angle of pull when the spirit level provided in the instrument is set to horizontal position.

System for Measurement Under Field Conditions

In order to develop an animal performance logger, instruments have been developed and evaluated under a collaborative program between AFRC Institute of Engineering Research, Silsoe (UK), and CIAE, Bhopal (India), for measurement of physiological responses of draught animals while working in the field. Simultaneous measurements of heart rate, respiration rate, body temperature, stepping rate, pull, angle of pull and speed of working are done using suitable sensors. These sensors are fitted on the animals and the implement being used. The leads of all these sensors are connected to a junction box fitted on the yoke. From this a common lead goes to a backpack battery-operated signal conditioning unit and to a logger. From the logger the data are fed to a battery-operated microcomputer and transferred to disc drive. The range of different sensors is given in Table 3.

The field data were analysed within about 1-2 hours of test run and printouts of statistically analysed data were obtained.

Table 3. Animal-implement performance variables monitored by the system.

Sensors fitted on	Variable	Range
Animal	Heart rate	40-160 beats/min
	Breathing rate	0-140 breaths/min
	Temperature	25-45°C
	Stepping rate	0-100 steps/min
Implement	Draught load	0-5 KN
	Draught angle	$0 \pm 45°$
	Forward speed	0-2 m/sec

Fig. 2. CIAE animal loading cars: top: 500 kg design; bottom: 300 kg.

Table 4. Annual utilisation of draught animal power in selected areas during 1985-87.

Location of the village	Animal type	Average annual utilisation (hours)	Operation wise utilisation, %				
			Seedbed preparation	Sowing	Transport	Weeding	Others
Near Bhopal	Bullocks	281	71	14.33	13.73	–	–
Near Raichur	Bullocks	828	65.62	15.38	10.46	8.35	0.19
Near Rewari	Bullocks	532	67.30	20.10	12.60	–	–
	Camel	499	44.03	18.08	37.84	–	–
Near Ludhiana	Bullocks						
a) Bullock farmer		795	26.20	5.00	68.80	–	–
b) Tractor farmer		582	0.10	2.62	97.28	–	–
c) Marginal		505	1.05	1.21	97.74	–	–
Allahabad	Bullocks	275	86.00	9.50	–	–	4.50
Pantnagar	Buffaloes	480	85.54	5.02	8.08	–	0.56
Udaipur*	Camels	1220	6.74	–	93.26	–	–

* Due to drought conditions camels were not used much for field operations.

Weather data including ambient temperature, wind velocity, intensity of sunshine and relative humidity were also recorded at the site of the test runs using portable units.

Efforts are also being made to add one more sensor to record oxygen consumption of animals during work.

Increasing Utilisation of Draught Animals

The annual utilisation of draught animals in different states and regions varies greatly. It ranges from about 300 to 1500 hours annually, whereas ideally they should be used for about 2500 hours giving 8 hours work for 6 days each week. The draught animals are mainly used for tillage, sowing, transport, and some interculture, water-lifting and cane-crushing operations. Their annual use is high in areas where the intensity of cropping is high, fodder crops are grown, the village is away from the town on metalled road and electricity is either not available or the supply is not regular. Wherever electricity and metalled roads are available farmers prefer to use electric motors for operating pumps, crushers, chaff cutters, etc., and modern methods of transport of people and material from villages to towns. In a recent survey conducted during 1985-87 at seven centres of the Animal Energy Project the utilisation of DAP was low in all those areas as shown in Table 4.

The annual utilisation of draught animal power could be increased in the following ways:

(i) By developing equipment for operations for which animals are not presently being used. In this direction efforts are being made to develop animal-operated harvesting machines for wheat, rice, sorghum, potato, groundnut, etc.; spraying and dusting machines and others so that the animals can be used for a higher number of hours for crop production activities.

(ii) By increasing use of animal power in agroprocessing. The concept of animal-operated agroprocessing has been developed and demonstrated where rotary power from a pair of animals is used for operating various machines for flour-making, flaking, oil extraction, cane-crushing, chaff-cutting, cleaning and grading, etc. Involvement of animals in these types of jobs will increase their annual utilisation. Machines run by 1-3-hp electric motors could be operated with a good pair of animals. This type of activity may increase the annual utilisation of animals by 1000-1500 hours.

If we recognise that the animal is available free of cost during idle periods for agroprocessing jobs, then the economics are favourable. However, if we compare agroprocessing jobs done by using animals versus electric motors then many of the operations are not economical.

Outputs of some of the machines operated by animals are: flour grinder 8-25 kg/hour; soyflaking 23.2 kg/hour; grain cleaner 120-450 kg/hour; paddy thresher 238-550 kg/hour; maize sheller 205 kg/hour throughput; groundnut decorticator 100-150 kg/hour; chaff cutter 380-1430 kg/hour depending upon the type of fodder; paddy cleaner 1100 kg/hour; duplex water pump 18 000 l/hour at 1 m head.

Improved Animal-Drawn Implements and Carts

The infrastructure for research on animal-drawn implements is fairly adequate. It is presently being done at CIAE Bhopal and 10 other ICAR institutes, agricultural universities, state implements research stations and by a few voluntary organisations totalling more than 40. A number of good manufacturers also keep on improving their products based on feedback from the farmers. ICAR has an All-India Coordinated Research Project on Farm Implements and Machinery with 16 centres located in different parts of the country. The project is being coordinated from CIAE Bhopal.

Shanmughan (1982) compiled the research work done on improved agricultural implements and machinery during 1950–80 and listed about 126 new developments on animal-drawn implements. Despandey and Ojha (1984) reported more than 18 organisations doing research on animal carts.

Important operations for which animal-drawn implements have been developed and are commercially available include: light land levelling, ploughing, harrowing/bakharing, puddling, planking and trash collection, sowing/planting and fertiliser application, weeding and interculture, harvesting, threshing, water-lifting, chaff-cutting, cane-crushing, oil extraction, grinding, and transport.

The draught requirement of most indigenous and improved animal-drawn implements is in the range of 30–70 kg and there is great scope for increasing their sizes by 50–100% to match the size of draught animals. This work is going on at seven centres of the Animal Energy Project.

A number of multipurpose animal-drawn tool-carriers have been developed. Studies on them have shown that their use can increase the coverage area from a pair of animals between 4 and 10 ha, depending upon the cropping and farming systems being adopted. Presently these tool-carriers are expensive and are not very popular, but efforts are being made to popularise them by subsidising their cost.

Animals are extensively used in rural transport systems. The bulk of crop harvest from field to threshing floor, firewood from field to house and small quantities of grains, fruits and vegetables from villages to marketplace are transported on animal carts. On hilly terrain, rural transport is mainly done on head loads or using pack animals. The population of pack animals in India in 1977 was 3.2 million consisting of about 916 000 horses and ponies, 89 000 mules, 973 000 donkeys and 1 068 000 camels.

For short distances, under field conditions and on field roads animal carts are more economical for loads of 5–20 kg. In operations involving high loading, unloading and waiting time, compared to travel time, trucks or tractor-trailers are not advantageous due to low utilisation. Transport of sugarcane, cotton, tobacco, jute and other agricultural products from field to processing factories are commonly done using animal carts. Transport of small quantities of materials in rural areas is most economically transported by animal carts.

It is estimated that there are about 15 million animal carts in India which transport about 1500–1800 million t of goods annually from 2–20 km distances, as compared to about 300 million t transported by goods trains. The investment in animal carts in India is estimated at 15 000 million rupees.

Milch and Pack Animals for Draught

Use of Milch Animals

Cows and buffaloes are being used on a limited scale for draught purposes in many parts of the world, though little research work has been done on the effect of work on overall productivity. Some studies show that milk production is not affected while others show that there are some reductions. Light work in fact was reported to stimulate milk production but heavy work caused a marked decrease (in some cases up to 80%).

In India in certain parts of Bihar, Orissa and Karnataka, cows having low milk yield are used for draught purposes. Leaving religious sentiments aside, there is a need to do systematic research to investigate the effect of work on milch animals and look towards the overall energy availability from cows.

Since the benefits of using cows for work as compared to bullocks appear so great, detailed investigation is required on the effect of work on overall productivity of draught cows. It should be determined whether it is work, heat stress, diet quality or a combination of these that are the main limiting factors to milk production and fertility of cows.

If milch animals could be successfully used for draught purposes without adverse effect on milk production, it will almost double the power availability from the present population of animals.

Use of Pack Animals

Pack animals (donkeys, mules, horses, camels and yaks) are mainly used for carrying loads on the back. Horses and mules in some cases are used for pulling tongas. Similarly donkeys and camels are also used in some areas for pulling carts. These animals are not used for field jobs in India.

Horses and mules were extensively used for ploughing, harrowing, seeding and other field jobs in European countries and in America. They should be used for field jobs in India. Some studies on donkeys have shown that they can exert more draught if they are used for pulling a cart or an implement than carrying pack loads.

Detailed investigations are being done on pack animals for their possible use for draught purposes to increase their work output.

Breeding for Draught Purposes

At present not much work is being done on breeding of animals especially for draught purposes. The breeding program is mainly for milk purposes, and out of the male progeny selections of animals for draught purposes are made. Hellikar, Haryana, Malvi, Nagori, Ongole, Gir, Kankerej, Khillari are the important breeds of cattle used for draught purposes. Efforts are now being made to produce good breeds of draught animals and their later management and care so that good quality animals are available for work suited to the climate, economics, agriculture and feed resources of the region.

Planning for Draught Animal Power

In keeping with the important role of draught animals in India research is being done in the following areas:

a) Breeding/selection and better management of draught animals;
b) Increasing the utilisation and efficiency of draught animal power system; and
c) Creation of infrastructure to support developmental programs.

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Draught Animal Power Research in Zimbabwe: Current Constraints and Research Opportunities

S. Tembo*

Abstract

In Zimbabwe's Communal Lands (CLs), a major constraint to increased agricultural productivity is timely access to adequate draught power to carry out tillage operations. This has become more critical as farmers have shifted from planting traditional seed varieties and have adopted high-yielding seed varieties (HYV).

The major source of draught power for most CLs farmers is oxen. This paper highlights how the lack of draught animal power (DAP) has become critical to crop productivity in CLs. It identifies land population pressure, inappropriate tillage methods and implements and poor exploitation of the available limited draught power in the working of the draught animals.

The paper finally outlines the DAP research agenda at the University of Zimbabwe. It proposes an interdisciplinary research approach to investigate the complementary factors involved in alleviating the identified constraints.

The research agenda addresses two factors: (i) Reducing the draught power requirements through innovative tillage methods and implements (low draught energy requirements); (ii) Improving the available (limited) draught power through improved nutrition regimes and strategic working of the draught animal.

Introduction

THE Zimbabwean agricultural industry is composed of two distinct sectors; the Communal Lands (CLs) and the Commercial Farming Areas (CFAs). Each of these sectors constitutes 40% or approximately 16 million ha of the total land area of Zimbabwe. CFAs are composed of about 4700 large-scale farms occupied under freehold tenure and employing approximately 280 000 workers. The CLs provide subsistence living for 80% of the community. They have absorbed 64% of the country's population growth over the past 15 years. Current estimates of farm households in the CLs vary between 650 000 and 850 000.

The CLs consist mainly of small farms about 3 ha of arable and approximately 5–10 ha of communal grazing land. In contrast, CFAs consist of large farms, the majority of which are 2000–3000 ha. Farming in CFAs is generally quite sophisticated. Cultivation in CLs is almost 100% by hand-hoe and/or by animal power and in CFAs is almost 100% mechanised. While most CLs farmers have adopted the use of hybrid maize seed, average yields in CLs are generally lower than those achieved in CFAs (Table 1).

Table 1. Comparative average yields (kg/ha), 1970–81.

Crop	Communal lands	Commercial farming areas
Maize	656	4732
Cotton	822	1650
Groundnuts	581	1710
Sorghum	516	1854
Soyabeans	–	1601
Finger millet	500	–

Source: Adapted from Chavhunduka (1982).

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Table 2. Land distribution by natural region ('000 ha).

	Rainfall (mm)	CFA	% of CFA	CL	% of CL
Natural Region I	>900	400	2.8	128	0.8
Natural Region II	750–1000	4325	27.6	1255	7.7
Natural Region III	650– 800	3240	20.7	2815	17.3
Natural Region IV	450– 650	4026	25.7	7307	44.9
Natural Region V	<450	3648	23.3	4774	29.3

Source: Adapted from Whitsun Foundation (1980).

Table 3. Area and population of communal areas, by province.

Province	Area (km^2)	Population	Population density (persons/km^2)
Manicaland	18982	693000	37
Mashonaland North	25344	421000	17
Mashonaland South	14910	565000	38
Matebeleland North	31045	320000	10
Matebeleland South	24189	357000	15
Midlands	27168	645000	24
Masvingo	21156	734000	34

Source: CSO Cited in Whitsun Foundation Data Bank No. 2 (1980).

Table 4. Land pressure in communal lands.

Pressure class	% of communal land area
In balance or under no pressure	33
Under some pressure	30
Under great pressure	13
Under excessive pressure	11
Under intolerable pressure	13

Source: Whitlow (1982).

Livestock, especially cattle, are a key component of the farming systems. Studies undertaken in two communal areas (Chibi and Mangwende) indicate that cattle ownership influenced cropping systems. Those with cattle had larger arable holding, better land preparation, timely planting and weed control, applied manure and achieved better crop yields (Shumba 1984). Livestock numbers in CLs are considered to be 3–4 times higher than the safe carrying capacities of these areas. This has resulted in overgrazing and a general decline in cattle ownership.

Agroecology Regions

Zimbabwe has been classified into five 'agroecological' or 'natural' regions, wherein agricultural development is conditioned by dominant natural characteristics such as rainfall and soil type/fertility. Generally the classification is in order of decreasing agricultural potential. Approximately 75% of CLs lie in Regions 4 and 5 (Table 2), where rainfall is commonly low (<700 mm), erratic and the soils tend to be sandy, acidic and of low natural fertility. Commercial cropping in the absence of irrigation is not generally considered a feasible proposition, thus dryland cropping is a risky undertaking with low yields and periodic crop failures. People live and farm these areas primarily as a result of circumstances, thus growing of staple crops in areas of marginal quality is a result of necessity rather than choice (Whitlow 1980).

Population Land Pressure in CLs

Population density in CLs averages 23 persons/km^2, which is over twice the safe carrying capacity of 10 persons/km^2 (Whitlow 1980) in Natural Regions III, IV and V, where more than 75% of the CLs lie.

Carrying capacity depends partly upon the quality of land, thus higher quality land can support greater numbers of people and livestock than poor quality land — if carrying capacity of the land is exceeded, then land degradation processes are initiated which can substantially lower the carrying capacity (Whitlow 1980). Consistent with Whitlow's observation, the variation of land pressure by province is shown in Table 3. Manicaland and Masvingo provinces, which have a poor land resource base (i.e. in Natural Regions III, IV and V), also have some of the highest population densities (37 and 34 persons/km^2 respectively).

Close evaluation of land pressure in communal lands (Table 4) indicates that nearly 40% of communal lands experience 'great to intolerable' land pressure, and nearly 70% of the CLs are already under pressure. The combination of a population growth rate of the order of 3.6%/annum together with overstocking and an ever-increasing rate of depletion of resources in these areas, means land degradation beyond redemption and self-perpetuating hunger.

Land Pressure and Draught Power

Factors Limiting Productivity in CLs

In the most classical sense of intensification of agricultural systems (Boserup 1965, 1981; Pingali et al. 1987), Zimbabwe's CLs farmers are well into the transition from human to animal draught power, and in some isolated pockets (in Region II) have advanced to tractor power. The control of tsetse flies (trypanosomiasis), the high population growth rate (3.6%) and infrastructural improvements have accelerated the replacement of the hand-held hoe by animal-drawn equipment for primary cultivation.

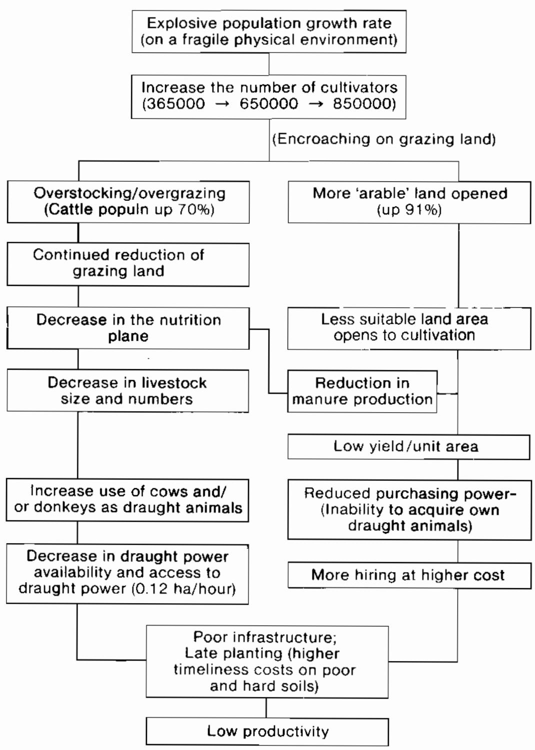
Most farmers now use oxen as the basic source of traction power for primary cultivation as well as for transportation of materials to and from fields. The expected gains in the shift from human to animal power have not been realised due to population pressure and the subsequent land degradation (Stubb 1977; Whitlow 1980).

Various estimates indicate that over the period 1961 to 1977 the number of CLs cultivators increased by 88% from 359 000 to 675 000. Total area under cultivation increased by 91% from 1.2 to 2.2 million ha at the expense of grazing land. Cattle numbers increased from 2 to 3.4 million resulting in overstocking on the already reduced grazing area.

Draught power availability expressed roughly as the number of cattle per cultivated hectare diminished from 1.7 to 1.5. Recent figures from the Planning Branch of the Agricultural Technical and Extension Services (AGRITEX) show an upward trend in the number of farm families and gross hectarage under cultivation in the period 1976–77 and 1984–85. Current estimates indicate the number of cultivators to be close to 850 000.

In the same period there was a 9% decrease in cattle numbers due to the breakdown in disease control during the war (1970–80). The drought of 1982–84 had the worst effect in Regions III, IV and V and slowed the rebuilding of the communal herd. The availability of draught power was worsened further with the ratio of cattle falling to 1.4 in 1985 (Rusike 1988).

The trend of declining draught supply is projected to continue well into the next century (FAO 1984). The current high population growth rate (3.6%) and the very high unemployment rates in the industrial and service sectors mean that the 'adverse' expansion of arable land at the expense of grazing land will continue. The net impact of these factors is accelerated land degradation, increased timeliness costs, reduced yields and the generally low productivity in CLs characterised in Fig. 1.



Source: Modified from Tembo and Elliott (1987)

Fig. 1. Low agricultural productivity in communal lands.

Draught Power Requirements

Most of the 850 000 cultivators own cattle. Economic studies of CLs farming systems (Bratton 1984; Shumba 1983, 1984; Mudimu 1983; Rukuni 1984) indicate that on average 75% of farmers own cattle. However, as these studies point out, mere numbers of cattle do not reveal the level of available draught power as not all animals are old enough or trained to pull implements.

In defining the draught power requirements one needs to define the source of draught power in the herd; for example, what percentage of the herd provides draught power, and how much draught power output can be expected from the draught animals?

In Zimbabwe the ox is the preferred source of draught power. Mudimu (1983) estimates the proportion of oxen in a typical herd to be 21% (Table 5).

The herd composition also shows that farmers attach greater importance to cows than to oxen. Cows serve a dual role as sources of manure and milk and draught power. Therefore, future intervention measures aimed at alleviating the draught power constraint would have to be cognisant of this factor to be effective.

Table 5. Typical herd composition (Buhera and Victoria districts).

Class of animal	% Distribution	
	Buhera	Victoria
Bulls	4.1	5.5
Cows	33.0	30.8
Heifers	14.8	17.1
Steers	10.0	7.0
Calves	16.3	18.2
Oxen	21.8	21.4

Source: Mudimu (1983).

Ownership of oxen reveals the extent to which cultivators face the problem of draught shortage. One needs to know what proportion of the cattle owners have adequate draught power. Animal draught power is a function of animal size; the larger the ox, the greater the draught power output. Adequate draught power (in the light of the shrinking Shona beast due to poor breeding programs) is a span of four oxen. In his studies, Bratton (1984) found that only 40% of CLs farmers had enough draught power (i.e. had four or more oxen; Table 6). These data are representative of most CLs, and indicate that a higher proportion of households do not have enough oxen and resort to using cows to supplement their draught requirements. The effect of this is a 30% reduction of power output (Howard 1980) and reduced field capacity resulting in delayed planting and reduced yield. Use of cows with current tillage methods and the high draught energy demand implements has been observed to reduce their fecundity (low calving rates, high mortality rates and small beasts).

Access to DAP

In Zimbabwe timely access to DAP is the major problem and a limiting factor to increasing the agricultural productivity of CLs farmers. Because cattle are weak at the beginning of the cropping season, or because they are not readily available, plantings (of the planting date-sensitive HYV seeds) are delayed. Seedbeds are inadequately prepared, weeding becomes a major problem and yields (in the marginal agroecological regions III, IV, and V) suffer (Tembo and Elliot 1987).

Examination of the cropping season reveals that the period of peak draught requirements is out of phase with the period of maximum percentage crude

Table 6. Ownership of cattle and draught.

Household characteristics	Wedza n = 184	Gutu n = 144	Chipuriro n = 97	Overall n = 425
Cattle ownership	%	%	%	%
Own cattle	75	83	82	79
Own 10+ cattle	26	31	27	28
Own no cattle	25	17	18	21
Draught ownership				
Own 2+ oxen	57	63	65	61
Own enough draught (4+ oxen) (objective measure)	35	46	49	42
Own enough draught (subjective measure)	33	47	39	39
Short of draught (2–4 oxen)	26	29	28	27
Draughtless (0–1 oxen)	39	25	23	31

Source: Bratton (1984).

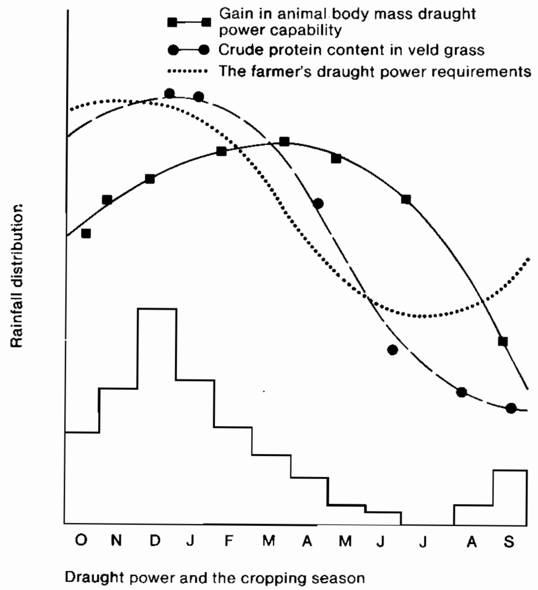


Fig. 2. Draught power and the cropping season.

protein content in veld grass upon which the cattle feed, and thus is out of phase with gain in animal body mass (Fig. 2). Herbage analysis of natural veld has shown that there is a high percentage (10.6%) of crude protein soon after the rains in December, and it declines to 1.6% around May as the grass matures. Digestibility of organic matter has been observed to decline in similar fashion and is directly related to gain in animal body mass. This means that in the absence of proper supplementary winter feeding programs, cattle lose weight, thus reducing their draught capacity at the beginning of the season when draught requirements are most needed.

What is of future concern is that growth rates in young animals are highly retarded due to this seasonal change. Add to this the nonexistent breeding programs in these overgrazed communal lands and you have the animal getting progressively smaller. Draught capability is directly proportional to size, i.e. the smaller the beast the less the draught capability, hence the need for a span of four oxen instead of the conventional two.

Research Opportunities

Experiences from research into DAP in Southeast Asia by Petheram et al. (1985) suggest that for DAP research to be effective it:

— must be related to an existing farming system and be aimed at reducing well-established constraints in that system;
— must be aimed at a particular target group;
— must be preceded by surveys of farmer circumstances, animal use and farming systems;
— must involve farmers from start to finish and be a long-term undertaking.

Workers on DAP in Zimbabwe (Bratton 1984; Shumba 1984, 1985; Mudimu 1983; and Blackie 1986) have in some ways approached DAP research in similar fashion. Their studies have also consistently identified the lack of draught power and timely access to draught power as the major constraint to increased agricultural productivity in CLs.

In trying to contribute to increasing the agricultural productivity of the typical CLs farmer, an interdisciplinary DAP research team at the University of Zimbabwe has put together a research proposal to look at the complementary factors in DAP. The group comprises an agricultural engineer, an animal nutritionist and an animal physiologist. The engineer will investigate energy-saving tillage systems and implements; the nutritionist will look into the nutritional requirements and ways of improving the nutritional plane per given tillage system and implement combination; and the physiologist will look at animal physiology and ways of maximising the available animal power output in both the methods of harness and time of working the animals. The research thrust proposes to address the above-mentioned issues in an interdisciplinary fashion in the hope that it will provide a farmer technology package that addresses all critical constraints. True, there are a number of other national research programs on DAP, under various umbrellas, but we argue that they will provide partial solutions to the identified problems, not because they are poorly designed, but because they tend to be narrow in their approach to problem identification.

Tillage Systems and Implements

Tillage

A major thrust of research into reducing the draught power shortage in Zimbabwe is the study of tillage systems which minimise draught energy requirements. In addition to this, the time required to carry out the tillage operation is also a critical feature of the studies as the lack of timeliness of operations is a major factor leading to depressed yields (Tembo and Elliot 1987). This is particularly true of the time of initial crop establishment where, for example, agronomic studies in Zimbabwe have shown that yield losses as high as 5%/week in some HYV of maize can be expected when planting is delayed after an optimum planting date.

There are a number of ways of reducing the energy requirements for tillage systems, given that energy is the product of force and distance. The first is to select those tillage operations which minimise the draught force required. Here the research effort will be directed at investigating the draught force requirements of the conventional mouldboard ploughing and ripping operations at the same depth in varying soil moisture content regimes. A data acquisition system similar to the one developed by O'Neill et al. (1987) will be used.

Preliminary work done by our Institute of Agricultural Engineering and the Agronomy Institute at the Department of Research and Specialist Services has shown that while there are no significant differences in yield under the different treatments, there is as much as 50% saving in draught energy requirement in favour of the ripping operation.

Investigations will also be directed at ganging implements to reduce the frequency of operations. While the draught energy required to pull the implements might be high, we believe that the total draught energy required per hectare will be a lot less. Also, with the complementary improvement of the nutritional plane and the strategic working of the animal, gains in terms of timeliness and soil conservation will outweigh the high draught energy per implement gang.

Implements

Machinery is required to support the farming system that has been formulated and not the other way round. The farming system is the dog and the machinery the tail, and it is accepted practice that the dog wags the tail (Inns 1979). In Zimbabwe the opposite has been observed. Inadequate mechanisation infrastructural support (poor machinery dealerships/repair networks in CLs) and limited research and extension services into appropriate tillage methods for CLs have contributed to low agricultural productivity (Elliot 1989). The most commonly used implement in CLs is the ox-drawn mouldboard plough and about 80% of the farmers in CLs own mouldboard ploughs (Rusike 1988). Use of this implement which inverts and pulverises the soil, encourages moisture loss and increases the susceptibility of soil loss through erosion, all of which are undesirable and should be conserved especially in Regions III, IV and V, has been marketed as the ideal implement. In the absence of innovative tillage methods, the high draught required for the mouldboard means that ploughing can only begin soon after the rains (when soil is moist), and would require large oxen to pull it, which is inconsistent with current draught power availability to the typical communal farmer, hence the draught constraint.

Research efforts are directed at designing implements to minimise the draught energy requirements per given tillage operation. Once energy requirements for ripper tines are established, together with comprehensive agronomic requirements for the above tillage methods, then an appropriate energy-saving implement package will be disseminated to farmers.

A review of toolbar carrier design as experienced in West Africa will be carried out. The slow rate of adoption of the toolbar carrier innovation elsewhere in Africa prompts us to proceed with caution.

Maximising Available DAP

The Nutrition Plane

Most livestock in CLs depend on the natural veld and, after crop harvest, crop by-products as feed sources. The veld in Zimbabwe declines in quality, from good in early summer to very poor by the end of May (Sibanda 1984). This decline in quality leads to low voluntary intakes of these roughages by ruminant livestock (Elliot 1967; Preston and Leng 1980). Supplementation with protein and/or energy sources has been advocated as a means of improving utilisation of such roughages (Elliot and Topps 1963; Preston and Leng 1980; Department of Research and Specialist Services 1977–81). Communal Land farmers in general do not feed supplements to their livestock and consequently weight losses during winter are the 'norm' in these areas. The effect of this weight loss in relation to beef production has been studied thoroughly (Department of Research and Specialist Services 1977–81). While the information generated by these studies does indicate the existence of nutritional stress in livestock dependent on veld and crop residues, it does not lend itself readily to solving problems related to draught animals.

The research thrust will seek to establish the effect of strategic supplementation and type and quantity of supplement on the work output of the draught animals. For example, should farmers (in the management of their draught animals) feed their draught animals small amounts throughout the dry season (June–November), or should they feed larger quantities for a shorter time, closer to their primary tillage operations, in order to ensure they have adequate draught power?

Time of Use of Draught Animals

One of the major problems outlined in the previous section is the poor animal condition due to poor nutrition during the months preceding and during the traditional ploughing time. An alternative approach to solving this problem is to undertake the major draught power requiring operations at a time when the animals are still in good condition. In particular ploughing and ridging operations could be undertaken immediately after harvest when the oxen are in good condition, and the soils have sufficient residual moisture for full depth ploughing (20–25 cm).

This system has been advocated by Agricultural and Technical and Extension Services for the last few years and has had a fairly good response. However, a number of traditional cropping and animal husbandry practices have to be altered if this practice is to be more widely accepted. The major problem is that harvesting is a labour-intensive operation. This operation needs to be undertaken as soon as possible after physiological maturity of the crop so as to enable ploughing or ridging to be done while there is still moisture in the ground and it is relatively soft. This leads to two major requirements. Firstly, the labour requirement is increased due to the increased speed at which the harvesting operation needs to be carried out. Secondly, the additional operations of drying the maize cobs and collecting the crop residue have to be carried out. Alternatively, stacking of the whole maize plant can be done and the separation of the two carried out afterwards.

The second aspect of improved time of use is the time of day at which animals are used and the total hours per day. For heavy work animals should be worked during the cooler part of the day, preferably for about 6 hours from 6 a.m. to 10 a.m. and 4 p.m. to 6 p.m. This increases the effective field capacity, i.e. the total area covered per given time (hectares/hour) (Tembo and Elliot 1987).

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Development of Draught Animal Power Systems in Ethiopia

Michael R. Goe* and Abiye Astatke**

Abstract

Use of animal power in Ethiopia is mainly confined to primary and secondary tillage using an ard plough called a *maresha* which is pulled by a pair of animals, usually oxen, under a ridged neck yoke. Equines (donkeys, horses and mules) are heavily relied on for packing and riding. Animal traction research which began in Ethiopia in the 1950s has followed two major directions: (1) development of implements to replace the *maresha* for more efficient primary cultivation; and (2) development of implements for secondary cultivation, with lesser emphasis on transport, operation of rotary-powered-geared machinery, water-lifting, earth-moving and land-shaping. Follow-up evaluations of implement performance at the smallholder level have been minimal. As a result there has been little adoption by farmers of new implements due to their cost, and difficulties encountered in maintenance and spare parts. Research on the animal component, e.g. management, nutrition and physiology has only recently received attention.

Introduction

DRAUGHT animals have been an integral part of agricultural production throughout most of Ethiopia for thousands of years; available evidence indicates that cattle were first used for ploughing in the latter part of the third millennium B.C. (Goe 1989). Ethiopia's extensive association with animal traction is atypical of other sub-Saharan African countries, where the use of animals for tillage and carting was introduced only during the latter part of the 19th and beginning of the 20th centuries (ILCA 1981; Pingali et al. 1987).

Ethiopia has the largest livestock population in Africa from which draught animals can be selected: approximately 26 million cattle, 3.9 million donkeys, 1.5 million mules, 1.6 million horses and 1 million camels (FAO 1986). Between 6 and 7 million oxen are used for draught in the country (EMOA 1980). Paired Zebu oxen are the main animals used for work, primarily tillage and threshing. In areas where oxen are in short supply, horses, mules and donkeys may be employed, either hitched with the same species or in mixed pairs. Infrequently oxen are yoked with equines or barren cows for ploughing. Donkeys are the primary pack animals, although horses and mules are also used. All three species of equines are used for threshing. Camels are relied upon heavily in the lower highlands and drier areas of the country for pack and transport; however, their use for tillage is minimal.

Numerous attempts have been made to develop implements to intensify and diversify animal power in the country, mainly for improved primary cultivation, and secondary cultivation operations such as weeding and planting. Efforts have also been made to use single animals and cows for traction and introduce alternative uses of animal power for transport, crop processing, land-shaping and water-lifting. However, follow-up evaluations of such research outputs at the smallholder level have been limited in scope. This paper reviews past animal

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traction research in Ethiopia, and discusses aspects of different technologies which could contribute to improved use of animal power systems within the country. For detailed information on particular research topics discussed, the reader is referred to those reports cited.

Research

Tillage Equipment

Ploughing of land at the smallholder level is carried out almost exclusively using the traditional ard plough *maresha* which is constructed from wood and has a narrow steel tip for penetrating the soil. It does not invert the soil like a conventional mouldboard plough, but rather functions like a breaking plough, disturbing or fracturing the soil as it passes through at variable depths. Attempts by the Italians in the 1940s to introduce a steel mouldboard plough at the smallholder level were unsuccessful because it weighed more than the *maresha*, required complicated adjustments and was difficult for the local oxen to pull, particularly on soils having a high clay content. In the 1950s, FAO reportedly developed a suitable plough, but no large-scale production and use occurred. Work was also carried out to design a low-cost harrow. Animal-drawn cultivators, while found to be suitable for certain tillage operations, were considered to be too expensive for the average farmer (Gabathuler 1953).

Between 1955 and 1965, a substantial amount of testing of implements using oxen, horses and mules was done at Alemaya College (Alemaya Agricultural University) in Harerge Province (eastern Ethiopia) and Jimma Agricultural Technical School in Kefa Province (southwestern Ethiopia). Implements tested included steel mouldboard ploughs, a single-disc plough, spike-tooth and disc harrows, and several different types of planters and cultivators (Burley 1955; Canaday 1959; Hendrick 1963; Wiggins et al. n.d.). Most of the implement research was conducted at the experiment station level, rather than on-farm. Reports tended to stress that the improved implements were suitable for accomplishing required tasks, but that lack of knowledge on the part of the farmer and weak animals caused the technology to be unacceptable (Canaday 1959). There seems to have been little recognition of the fact that problems regarding farmer adoption were largely due to equipment being inappropriate for the power source, complicated in design and operation, difficult to repair and too costly.

A major effort was initiated in 1968 by the Implement Research Section of Chilalo Agricultural Development Unit (CADU; name later changed to Arsi Rural Development Unit, ARDU) in Arsi Province (south-central Ethiopia) to design, test and develop tillage implements and carts. Later, investigations were carried out with threshers and water-lifting devices. Numerous trials were conducted to evaluate both locally manufactured and imported ploughs and toolbars from the US, India and countries in Europe (CADU 1969, 1970, 1971a). Although studies demonstrated that the use of a mouldboard plough and harrow could reduce cultivation time by up to one-half of that required for the *maresha*, yields were not significantly increased.

The development of a suitable mouldboard plough as a replacement for the *maresha* continued to prove difficult through to 1980, with major obstacles being cost, weight, durability and difficulties in getting repairs made at the artisanal level. Past attempts to modify the *maresha* have included the 'Jimma plough,' in which the wooden soles and share were substituted with flat iron strips and a vertical knife, the 'Vita plough,' in which the complete ard head of the *maresha* was replaced with a metal mouldboard assembly, and the 'Ardu plough,' a modified version of the Vita design (CADU 1970; Teclemariam Berhane 1979).

Trials demonstrated that while the Jimma plough provided better tillage than the *maresha* on loose soil, it had no advantages when used on fallow plots or those having heavy clay soil. It was also more costly than the *maresha*. Tests with the Vita prototype indicated that design changes in the mouldboard assembly and angle of the handle were necessary to improve its tillage performance. These and other modifications were subsequently incorporated into the ARDU plough. However, this plough was rejected by both farmers and extension personnel because it was too heavy to be easily transported to and from the field, the metal frame which was attached to the beam to support the mouldboard assembly did not provide adequate stability, the durability of the share and mouldboard were poor in relation to the high cost of the plough and it had a higher draught requirement than the *maresha* (ARDU 1980). There has been little adoption of these three implements in the country.

Simple wooden-framed spike-tooth harrows were first produced by CADU in 1969, and more than 300 were distributed within Arsi Province by 1971

(CADU 1971b). Research station trials as well as limited on-farm studies have shown that a harrow can provide more uniform seed covering than the *maresha* and can help reduce erosion by leaving a coarse cloddy surface (CADU 1969; ARDU 1980). However, farmers complained that it was difficult to transport the harrow to and from their fields, i.e. the harrow had to be carried by a donkey or horse, thereby occupying an animal when it could be utilised for packing or riding. Thus, skids were designed so it could be turned over and dragged by oxen to the field. At present, distribution of harrows continues to be concentrated in Arsi Province, where ARDU, with the assistance of extension personnel, carries out much of its development and testing of equipment. Cost is a primary factor limiting the use of harrows. In addition, many areas in the highlands are too rocky for the implement to be used effectively.

In 1976 the Agricultural Engineering Department of the Institute of Agricultural Research (IAR) began to develop and test farm tools and equipment appropriate for agricultural conditions in Ethiopia. One study evaluated an implement package consisting of a mouldboard plough, spike-tooth harrow, imported toolbar and hand-operated planter for crop production under irrigated conditions in northwestern Harerge Province (Teclemariam Berhane 1979). With these implements, the 2.5 ha normally cultivated by two oxen could be increased to 6–8 ha, but weeding and harvesting were major bottlenecks. A crucial factor against such a package being used at the smallholder level was that no organisation existed within the country which was able to produce implements similar to the imported ones or supply spare parts. Adoption of the technology was also dependent on the untested assumption that several families would have to pool their resources to purchase the implements, an important socioeconomic aspect which had yet to be thoroughly investigated by the end of the study.

Later, IAR established the Agricultural Implements Research and Improvement Centre (AIRIC) whose mandate included selecting, testing and evaluating animal-drawn implements developed in the country and elsewhere. Research has been carried out on ox-carts, levelling implements and winged-chisel and mouldboard ploughs. Limited success has been reported with an improved version of the imported Italian 'Nardi' mouldboard plough in a few collective farms in the country (Menkir W/Kiros 1987).

The Farm Implement Division of the Ethiopian Ministry of Agriculture (EMOA), established in 1982, is responsible for the improvement of agricultural implements used in the country, including draught animal equipment production, testing and development of harnesses and yokes, and the use of equines for draught. Most of the implements tested are produced by IAR workshops in Nazareth and Bako, located in southeastern and western Shoa Province, respectively, or by ARDU. The Rural Technology Promotion Programme (RTPP), also within the EMOA, imported about 30 wheeled toolcarriers which were distributed for evaluation in farmer testing centres on collective farms in different parts of the country. The implements were found to require more draught force than the indigenous animals could produce and durability of parts and maintenance were reported as major problems (Menkir W/Kiros, pers. comm. 1987).

The Relief and Rehabilitation Commission (RRC) has tried to integrate the use of draught animals and mechanisation by employing tractors for primary tillage and oxen for secondary ploughing and harrowing in some resettlement areas in the western part of the country (RRC 1981). Mouldboard ploughs have been imported from Kenya, India, UK and the Netherlands, but were rejected by farmers due to their weight and high draught requirement (Aberu Ketema 1987).

Since 1979, the International Livestock Centre for Africa (ILCA) has been conducting research on tillage implements in relation to their power requirements, associated cultivation and weeding times, and crop yields under different soil types. Details of this work can be found in the reports of Abiye Astatke and Matthews (1982, 1983, 1984). Principal findings showed that use of a steel mouldboard plough can reduce by at least one-half the cultivation time normally required when ploughing with the *maresha*. This level of reduction agrees with figures obtained from similar trials reported by CADU (1970, 1971a). In another study, use of either a mouldboard plough or spring-tine cultivator for initial tillage, followed by secondary tillage and (or) seed covering using a zig-zag harrow did not result in significantly better weed control than the traditional system which employs the *maresha* for all three operations. No significant differences in yields were observed between any of the three implements.

Research on the use of single indigenous oxen with a modified *maresha* was started at ILCA in

1983 and was intended to benefit the large number of smallholder farmers with only one animal (Gryseels et al. 1984; Gryseels and Jutzi 1986). On-station and on-farm tests were carried out over a 2-year period. Generally, however, test conditions were more favourable than those on the majority of farms where the innovation was intended to be introduced. Large-scale testing was planned, but was curtailed because of circumstances caused by the Ethiopian Famine in 1984–85. The single-ox system was perceived to be a low-cost, low-risk technology which could assist a large group of farmers in post-drought recovery when oxen were in short supply and high priced. It was on these bases that it was introduced in significant numbers by nongovernmental organisations.

Major adoption problems were encountered, mainly due to the poor condition and fitness of oxen for work, difficulties of maintaining and controlling the implement on stony and hilly fields, and cultural barriers to using this change in tillage method. Benefits anticipated to derive from introduction of this technology have not been realised. It is most likely that the single-ox technology will be sustained by a small number of farmers and evolve in the longer term as a means of cultivation by smallholders for secondary ploughing and seed covering in those areas where oxen ownership is limited.

Further research is required to address nutritional needs of oxen worked as singles and to devise a more robust implement. The experience with this technology highlighted the importance of rigorous on-farm testing under the full range of conditions and circumstances where the technology is to be extended.

Other ILCA modifications to the *maresha* have included a wooden mouldboard 'terracing' plough, seeder attachment and a broad-bed maker (BBM) (Abiye Astatke and Jutzi 1985; Jutzi et al. 1986, 1987; ILCA 1988). The BBM is in its second year of being tested in on-farm verification trials within several provinces in conjunction with the EMOA. Preliminary field results indicate that these implements, particularly the BBM, have a high potential for improving the management of Vertisols (Jutzi and Mesfin Abebe 1986; Jutzi et al. 1987). On-station testing of the BBM as a prototype 'toolbar' incorporating a blade harrow and row planter is also being carried out.

Carts and Sledges

Tasks performed by animals are traditionally limited to tillage, threshing, packing and human transport. It was not until around the time of the Italian occupation (1936–41) that the use of horses, mules and donkeys for carting became established within and around the larger cities and towns, and in coffee-growing areas (Vitali and Bartolozzi 1939). Carts brought into Ethiopia by the Italians were preassembled or constructed by artisans using local materials and imported components such as axles, wheels and bearings. During the 30 years following independence, the use of animal-drawn wheeled transport increased very little within the country (Gabathuler 1953; Huffnagel 1961; CADU 1969). This situation occurred primarily because the infrastructure supporting such technology continued to rely heavily on costly imported components.

In 1969 CADU began building several prototype two-wheeled carts for single horses or donkeys and paired oxen. The axles were forged in the country, while the iron-rimmed wooden wheels with metal bushings were imported. The prototype carts were loaned by extension personnel to interested individuals in Arsi Province for testing and evaluation, and also to determine farmer demand and the possibility of manufacture by a small-scale local industry (CADU 1969). Some fabrication of ox-carts using iron wheels and axle assemblies from pieces of discarded machinery or vehicles was also carried out by CADU, but these offered limited possibilities due to lack of old equipment and spare parts (Kline et al. 1969).

In 1971, the production of iron-rimmed wooden and steel-wheeled carts made of locally manufactured components began. Problems were encountered in training artisans to adhere to specifications in shaping and building the wooden wheels. Trials showed that steel-wheeled carts outperformed those with iron-rimmed wooden wheels, with any breakage being attributed to overloading, rather than defective design or construction. However, attempts to make the wheels at the artisanal or small workshop level resulted in a product of inferior quality compared to those produced by a large, well-equipped tool factory. Although the high cost of steel wheels favoured intensifying efforts to produce higher quality iron-rimmed wooden wheels, field testing ultimately favoured the use of steel-wheeled carts (CADU 1971a).

ARDU presently manufactures steel-wheeled horse, donkey and ox carts, based on a design similar to that introduced earlier by CADU. Most of these carts are found within Arsi Province, although there is limited use of them on government and international research stations or in resettlement areas. Strong extension support and credit facilities have made farmers in Arsi Province generally more receptive to the use of carts than in other parts of the country. Recently there has been an increase in the demand for donkey and ox-carts in the larger resettlement areas where roads have been constructed and local artisans have been trained to make repairs and are provided with materials. ARDU also makes carts with mounted tanks for hauling water, as well as enclosed carts for transporting meat, but these have limited distribution.

Although the use of carts on farms within Ethiopia is not widespread, two-wheeled pneumatic-tyred carriages (called *garees*), usually pulled by a single horse, are heavily relied upon to transport people and goods within and on the outskirts of many urban areas. Heavy duty two-wheeled carts fabricated from wheel and axle assemblies of discarded vehicles are also used on a small scale. Use of draught animals to pull four-wheeled wagons is limited primarily to the cities of Asmara and Assab in the north and northeast parts of the country, respectively. In and around towns in southern Shoa Province, within the vicinity of Lake Ziway, firewood and fuel and water drums are commonly transported on locally constructed wooden carts that have small-casted spoked wheels and which are pulled by one donkey. Occasionally, paired oxen are employed to pull these carts on dirt roads in the same area.

Sledges have been employed in Arsi Province for nearly 50 years to transport crops from fields to threshing areas (Vitali and Bartolozzi 1939; Kline et al. 1969). Infrequently, their use is observed in other provinces. They are locally constructed from wood and are pulled by a team of oxen. Information on dimensions, draught requirements in relation to size of load and ground surface is lacking.

Scoops

ILCA began on-station testing of ox-drawn scoops for excavating surface ponds in 1983. This work was later extended, with the assistance of the EMOA, to off-station trials in which two ponds were constructed. The suitability of this technology to provide improved water resources in the rural areas of the country has resulted in the distribution of approximately 1300 scoops to the 14 provinces of Ethiopia by the EMOA. Problems encountered are primarily organisational. For details of this work see Abiye Astatke (1984), Anderson and Abiye Astatke (1985), Abiye Astatke et al. (1986a), Abiye Haile Selassie and Cossins (1985) or Starkey et al. (These Proceedings).

Animal-Powered Machinery

Some limited on-station testing of animal-powered threshers was carried out in the late 1950s (Canaday 1959) and 1960s (CADU 1969). Tests conducted with an imported rotary-geared thresher showed that animals were unable to maintain the necessary power to operate the thresher at optimum speed, resulting in threshing losses. The machine was too costly for farmers and spare parts had to be imported. Another drawback was that the thresher was basically stationary and could not be easily transported.

There has been very little research done using animals to power pumps (Beyene Megersa 1980), mills or oil presses within Ethiopia.

Working Performance

Data regarding the amount of force and power output developed by paired oxen when pulling different types of tillage implements under various agronomic conditions are contained in several reports (CADU 1969, 1970; Beyene Megersa 1980; ARDU 1980; Abiye Astatke and Matthews 1982, 1983, 1984; AIRIC 1986a,b, 1987a,b,c). Studies were carried out on research stations and involved comparisons of the *maresha* and mouldboard ploughs, harrows and cultivators. Reports prior to 1980 contained little information about methodology employed. Those published after this are generally more comprehensive. With the exception of a 2-year study carried out on 24 farms (Goe 1987), data on working performance of oxen at the smallholder level are lacking.

Nutrition and Physiology

Research on feeding and nutrition of working animals in Ethiopia has only recently received attention. An ILCA study examined the effect of diet restriction on working crossbred and local single oxen (Abiye Astatke et al. 1986b). Both groups on the restricted diet were able to perform work equally as well as the two control groups over the 23-week period. The restricted local and crossbred oxen lost weight at the same rate, but the local oxen lost more. Another ILCA study examined the effect of work on feed intake and nutrient utilisation of crossbred and local oxen (Soller et al. 1986). Results showed intake to decline during work periods for both groups, although digestibilities and nitrogen balance were not affected. Local oxen had higher digestibilities of plant cell wall and lower energy needs than crossbreds, based on feed intake relative to $W^{0.75}$.

A 2-year on-farm study to determine the utilisation of feed resources by working oxen was carried out (Goe 1987). Results showed stored hay and cereal crop residues to be much higher in apparent digestible dry matter and metabolisable energy and crude protein than was previously thought. Where supplies of feedstuffs were adequate, energy needs for maintenance and work were met, except during the latter part of the ploughing season.

Studies have been done by IAR to determine the draught capacity and physiological responses of three types of crossbred oxen and local oxen when pulling different loads on a test track (Adunga Kebede et al. 1989; Takele Gemeda et al. 1989). Results showed local oxen to have higher respiration rates, but lower body temperature than crossbreds. Significant differences were observed in speed of travel and power output between the crossbreds and between the crossbreds and the local oxen. Power and energy output, expressed per 100 kg liveweight, was similar for all the crossbreds, but significantly higher than for locals. Conclusions regarding respiration rates and energy output between crossbreds and local oxen are in conflict with results of similar studies.

Use of Cows

An on-station study to determine the effects of using pairs of crossbred dairy cows for draught showed that at low levels of work and with proper feeding and management, work had no significant effect on milk production and reproductive performance (Agyemang et al. 1985). A follow-up 2-year collaborative study between IAR and ILCA is being carried out to determine nutritional needs for work, milk and reproduction by working the crossbred cows singly at rates and periods similar to those encountered on-farm.

Training, Harnessing and Packing

Except for some preliminary work carried out by CADU in which oxen were trained for work with the aid of nose rings and reins (CADU 1969; Kline et al. 1969) and on-station activities of ILCA that involved the use of reins to control teams of paired oxen, animal training and handling has received little attention.

Minimal work has been done to develop and test harnesses or yokes (Hendrick 1963; CADU 1969; Wiggins et al. n.d.). A single-ox yoke was developed by ILCA and some work has been done with equines by the EMOA. Where equines are employed for light carting a simple breast band harness is most commonly used. Farmers using equines for ploughing attach a second beam or crosspiece to the bottom of the vertical pegs on the traditional yoke and construct a padded collar.

Logging

There was limited use of oxen and mules for timber extraction in the central and southern forest areas of the country during and after the Italian occupation (Logan 1946) and in the late 1960s (CADU 1969). At present animals are not used for logging, although use of paired oxen or donkeys or single donkeys, horses and mules for dragging saplings or roughed boards to homesteads is common within many parts of the country.

Conclusions

Animal traction will continue to play a major role in agricultural production at the smallholder level in Ethiopia. As this review points out, a substantial amount of research on various aspects of this technology has been carried out over the past 35 years. There is an urgent need to draw together the results of this research, recognising past mistakes, and reorient future work so that the full potential of animal traction can be realised. Farmers must be included from the outset in evaluating draught animal technologies since they are the ultimate users. This point cannot be overemphasised. Well planned on-station studies must be followed up by extensive on-farm verification trials to properly evaluate a new technology.

To date, only minimal achievements have been reported by any national, international or private organisation in extending the use of mouldboard ploughs to replace the *maresha* or to introduce other implements for secondary cultivation. A large amount of information exists regarding animal-drawn implements which should be evaluated prior to carrying out new research. Tillage conditions, ease of operation, durability and maintenance are key points to be considered. The *maresha* continues to be the best implement available to farmers given their resource base and tillage conditions. Until major changes are made in the current level of extension support within the country, artisanal capability and access to tools and supplies, other animal-drawn tillage implements will not be widely adopted.

More attention should also be given to the development and promotion of wheeled transport in the rural areas, particularly donkey carts. Additional research should be conducted to determine the quantity and quality of the total feed resource base available to farmers in different areas of the country, as well as feed requirements for working oxen. If farmers are feeding animals at levels beyond what is required, then a certain percentage of feed could be diverted towards improving the productivity of other livestock or extending the period over which oxen are fed. Results from the study of Abiye Astatke et al. (1986b) raise some questions as to whether loss of weight within a certain range is actually detrimental to work output of teams. As it now stands, very few farmers make a concerted effort to regularly feed small stock, i.e. sheep and goats, most often stating that stored feed supplies are not adequate. If extra feed could be diverted from the oxen, it may be possible to fatten these animals for sale. Heifers and nonlactating females would also benefit from diverted feed supplies. Another advantage is that oxen could be utilised for work during the dry season, e.g. pond construction, terracing or water-lifting. The potential of expanding the use of equines for tillage operations and carting should be investigated.

Distribution of crossbred cows is increasing within certain areas of the country and it is likely that crossbred males will become more available. Additional research is needed to determine the extent to which current systems can support a crossbred team. Trials by Soller et al. (1986) indicate that when intake is expressed as $g/W^{0.75}$ crossbred oxen required more energy than local indigenous oxen and had lower digestibilities, particularly of plant cell wall. Indigenous teams have the ability to pull the *maresha* under existing tillage conditions and are more resistant to disease and stress. Unless it can be substantiated that there are definite benefits to be gained from the use of crossbred oxen, it may be more productive to use local animals for draught and fatten crossbreds for sale. Similarly, more information and on-farm testing is required regarding the use of lactating crossbred females at the traditional level. Farmer management, available resource base, production environment, and overall profit will determine the suitability of these technologies.

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Draught Animal Power in The Gambia

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Abstract

This paper gives a brief review of the developments and utilisation of animals for draught purposes in The Gambia and subregion. Draught animals are not used intensively, which could be attributed to a number of factors, such as animal trypanosomiasis, limited work force and financial resources and cultivation practices. Some of these factors are changing, making the use of animals for draught purposes a possibility, although there are still numerous constraints to their use as draught. Regional cooperation in the field of draught animal research is a necessity if crop production is to be increased to meet the demands of an increasing population. The use of draught animal power in The Gambia and the subregion is not restricted to crop cultivation. Animals are used as a means of transportation in rural and some urban areas.

History of Animal Traction

THE use of animal traction in The Gambia has been in existence for many decades, and a draught animal census was included in a report by the Colonial Secretary in 1909. In the mid 1950s ox-ploughing schools were established. The aim of these schools was to train farmers to use ox as draught animals, to encourage mixed farming practices which would increase crop production. This program worked well. The ox-ploughing schools developed very rapidly throughout the country. By the early 1960s ox-ploughing was the central feature of the government's agricultural extension effort. The ox-ploughing schools were later changed to mixed farming centres. The program clearly demonstrated that by using draught animal power both the area under cultivation and production increased considerably. The farmers know that it is in their interest to use draught animal power in their farming systems. The drought period of the early 1970s slowed down the adoption process, however.

Animal traction research in The Gambia was basically on equipment trials. These trials were conducted on the following farming implements between 1955 and 1985:

a) Emcot Ridger;
b) Wheeled tool-carrier for weeding;
c) Siscoma *Sine houe* toolbar;
d) Super Eco seeder;
e) Prototype seeder/fertiliser applicator; and
f) Prototype maize cultivator.

The results obtained at the end of these trials were encouraging, but the technologies were often too expensive for the smallholders.

Present Situation

As cited above training at the mixed farming centres was exclusively concerned with oxen. The policy has now changed, and in 1986 a task force on animal traction was created by the Ministry of Agriculture with the objective of developing quantitative information on the population dynamics of equines throughout The Gambia. This would include sex ratios, mortality and foaling rates. Mortality and foaling of equines were identified as possible problem areas during a rapid survey in 1986 by the animal traction task force (Cham et al. 1986). This is a clear indication of policy change. Equines, particularly donkeys, are thought to have rapidly increased in popularity. Starkey (1986) concluded that during the period 1965 to 1985, donkeys changed from being of minor importance to their present status as the dominant

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draught animal in The Gambia. The extent and rapidity of this change is illustrated by the fact that in their wide-ranging and highly detailed study of Gambian agriculture between 1972 and 1975, Dunsmore et al. (1976) put particular emphasis on ox cultivation, and made only passing reference to equines.

The 1987–88 national draught animal population was estimated at 15 000 horses, 20 000 oxen and 28 000 donkeys (PPMU/NASS, unpublished data). Presumably draught animals are owned by 45% of the farming households, and this number is rapidly increasing due to the fact that donkeys are cheap and obtainable from Senegal. The Super Eco Seeder from Senegal uses equines and is now very popular.

Regional Activities in DAP Research

In Senegal, the National Agronomic Research Centre in Bambey has been actively engaged in various aspects of draught animal research, to increase groundnut production in Senegal, by reducing the sowing time and improving crop cultivation practices. As a result of these research efforts the smaller *houe occidental* for cultivation using equines was produced and it is very popular in the region.

SODEVA, a government agency, also embarked on replacing bulls with cows for draught purposes. This research is still under way and a number of farmers have accepted the idea. Farmers concluded that with the cow, they get work, milk, manure, calves for replacement and accumulation of capital savings. Now their use for draught has great impact in some regions especially in the Sine Saloum area, where cows are performing 27% of the draught.

'Oxenisation' of the Ndama cattle was also carried out in Sierra Leone, just like The Gambia. The Ndama cattle is a trypanotolerant breed and greater attention should be given to it in the field of draught animal research.

Constraints

1. Limited labour and financial resources are the major constraints in the promotion of draught animal power in the subregion.

2. There is a lack of feed resources for the long dry season.

3. Equipment and implements are difficult to obtain or maintain.

4. Animal trypanosomiasis is a limiting factor in using equines and more tolerant breeds of cattle in this subregion.

5. Work oxen are expensive for smallholders.

Conclusions and Recommendations

It is a well-established fact that the use of draught animal power in this subregion is a viable alternative, since mechanical agriculture is absent or not profitable. Smallholders form the largest percentage of the farming community, therefore research efforts should be geared towards their needs. Capital is the main obstacle in the use of animal power in this subregion. It will therefore be necessary to provide credit facilities to smallholders. It will also be appropriate to redress the spare part shortages through better training and support facilities to the village blacksmiths, who play an important role in the field of animal traction in the subregion.

Future research activities should also explore the possibilities of utilising the Ndama cattle in rice cultivation, since the Ndama is trypanotolerant.

Regional cooperation through networks should be encouraged so that the flow of relevant information in draught animal research will get to researchers.

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Section 3

Farming Systems Research Relating to DAP

Farming Systems Research Relating to Draught Animal Power: An Overview

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Abstract

Farming systems evolve by farmers assessing variation, selecting preferred options and rejecting the inferior. Selected options generally optimise resource utilisation rather than maximise production. Farming systems research (FSR) facilitates selection and rapid evolution under realistic conditions. Some FSR programs have developed technologies on mechanised stations but have often produced animal-drawn implements difficult to manoeuvre in farmers' fields and heavy for village animals. FSR researchers concluded that one recent, major attempt to develop new animal-powered systems wasted time by not involving farmers. FSR involves diagnosis of constraints and needs, design of possible solutions, testing of preferred options and dissemination of farmer conclusions; farmers and farm communities are involved at all stages. Quantification of complex farming system interactions is difficult; subjective judgments following rapid rural appraisal may yield valid conclusions more quickly than 'objective' surveys. With FSR, farmers make technological choices from options. Farmers may reject technically superior options for valid socioeconomic or personal reasons. Researcher preferences should not be apparent in value-judgments: epithets like 'improved' have been wrongly ascribed to implements, harnessing and techniques before farmer assessment. FSR implies realistic research; optimistic assumptions should be avoided; animal traction technologies should be appropriate to existing animals, field conditions and economic circumstances. FSR philosophy involves common sense, and combines comparative advantages of researchers and farmers.

Introduction

THIS paper is intended to introduce the topic of farming systems research (FSR), review some farming systems programs involving animal traction and discuss some of the implications of applying FSR principles and techniques to animal traction studies. The first part of the paper introduces FSR, by presenting it in an historical perspective. The major elements of FSR will then be summarised and the relationship between FSR and disciplinary studies will be touched on. Finally some of the practical problems experienced by programs using an FSR approach to study animal traction will be discussed.

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Animal Traction Research

Farmers' Own Research Techniques

Most present farming systems in tropical countries have been developed by generations of farmers trying to optimise their production in light of their needs and the physical, biological, climatic and socioeconomic constraints of their environments. The word 'optimise' is particularly important, for one of the clearest research lessons of the 1960s and 1970s is that while many researchers were devising technologies that would **maximise** production, farmers only adopted those that helped them to **optimise** their production; modified traditional technologies that resulted in reliable low-to-medium output were generally preferred to innovative high-input, high-output and high-risk systems of production.

For generations, farmers have ensured that their complex and dynamic farming systems have been constantly evolving due to two major processes: variation and selection. The analogy with biological evolution (or artificial breeding) is quite apt, for the refinement of organisms, techniques or implements has been based on the natural or artificial selection of the preferred options. If either variation or choice were lacking, there was no scope for improvement. Successful breeding programs have involved the multiplication of the chosen and the culling of the inferior options; selection has always involved rejection. This has also been true for harnessing, implements, cultural operations and animal-training techniques; where there was no variation and no selection, there was no evolutionary improvement. Historically, large or small changes in draught animal technologies have been made by innovative farmers themselves, often working with village artisans. Naturally the technologies were tested and selected within the local farming systems and the choice of whether to use the old or new technique or design was taken by the farmers themselves and their neighbours. This system of evolutionary progress has led to the development of the large range of traditional animal traction technologies in use today. Such an evolutionary process has existed in all farming communities, and continues throughout the world (Richards 1985). The process is intrinsically efficient in the long term, but very slow by the standards and aspirations of modern governments, research workers and development projects. As will be discussed later, the basic evolutionary process can be speeded up by providing farmers with more sources of variation and allowing them a greater degree of selection.

The major innovations of the European 'agricultural revolution' of the eighteenth and nineteenth centuries were the result of traditional evolutionary development, accelerated by the significant economic benefits that could be achieved with success. Farmers (often wealthy 'gentleman-farmers') identified specific constraints and then worked with blacksmiths (some of whom became manufacturers) to develop new implements to overcome the constraints. The implements were designed for the existing farming conditions and appropriate operational techniques for their use were developed on the farms of the innovators. This resulted in the rapid evolutionary development of animal traction: naturally not all were successful for the process involved the creation of variation, selection of the preferred and rejection of the less favoured technologies (implements, animals, harnessing systems and operational techniques).

Private Sector Research/Development Techniques

The evolution of animal traction technologies has largely been the result of 'private sector' initiatives. Smallholder farmers and village blacksmiths are here considered as part of the informal, private sector, and over the decades and centuries it is they who have done most to modify and adapt animal traction through trial and error. Larger profit-maximising farms, estates, production companies and manufacturers have also carried out basic research/development activities that have resulted in new or modified systems for using draught animals. Such work has almost always been carried out in the environment in which the technology was to be used. For example commercial estate farms have themselves developed animal-drawn transport for use in such estates and large commercial farms have developed systems for large-scale farming using draught animals. In several parts of Africa cotton production companies have worked with smallholder farmers to develop systems of growing cotton using draught animals. In such circumstances, research/development work was usually aimed at identifying and overcoming specific constraints, the work being undertaken in close cooperation with participating farmers.

Public Sector Research Techniques

A 'public sector' of formal, government-financed agricultural research institutions and programs started to be significant only in the present century. Thus the major expansion of government-funded research programs and research stations coincided with the period when tractors and stationary engines were replacing animals as primary power sources for capital-rich farms. As a result, there have been few research stations in the world that have not been developed and operated using capital-intensive machinery. In industrialised countries, this has not been too serious, as many farmers have been able to follow similar paths to mechanisation, and the research stations have not been markedly dissimilar to the conditions found on the more technologically advanced farms in the area.

However, in developing countries, research stations have seldom borne much resemblance to the local farming systems. When establishing national, regional or international research stations, favourable sites have been identified, that have had good soils, reliable water supplies and reasonable access to national communication networks. Research stations have usually been designed for research on 'modern' farming systems based on large stump-free fields and tractor power. This was not too serious in countries such as Brazil, Kenya, Mexico, Morocco and Zimbabwe that had two distinct farming sectors, the relatively affluent, large-scale farmers and the numerically dominant smallholder sector; in such countries, the research stations have at least provided an environment comparable to one of the two sectors. However, the majority of developing countries have few large-scale farms producing food crops; thus since their creation (often 30–60 years ago), the large, open fields of the research stations have frequently had little resemblance to any farms outside the perimeter fence.

During the period 1950–80, much of the agricultural research in tropical countries was carried out under the controlled and exceptional conditions of such research stations. Fields were large, relatively level and stump-free. Draught animals were large, well-fed and healthy, and often of exotic breeds or crossbreeds. Hired labour was always on-hand, and workshops were readily available should rapid repairs be needed. It was not uncommon for agricultural researchers to work in their particular areas of technical research (such as agricultural engineering, animal production or crop breeding) with relatively little professional interaction with colleagues in other disciplines. Indeed ministries were often divided so that people working on crops, livestock and implements had little chance of meeting under their normal professional routines. At that time social scientists were rarely associated with the technical programs, and they naturally tended to publish their findings in specialised professional journals of anthropology or economics, seldom read by the agriculturalists. Farmers were occasionally allowed onto the research stations for demonstrations and field days, but their farms were seldom visited by researchers and it was rare for them to be consulted as experts in farming under the prevailing conditions.

This overview contains broad generalisations. Of course throughout the period there were many exceptions and some very good, farmer-orientated research teams working both on-station and in farmers' fields. However, the overall criticism has validity.

Largely as a result of the research conditions and the prevailing attitudes, researchers tended to produce high-quality technologies suitable for use on the research stations. In line with national policies government-funded technologies were generally intended to **maximise** local production. This was the era of 'green revolution' publicity. The various technical 'solutions' were often promoted in classical 'top-down' education/extension programs with associated financial credit and subsidies available only on the specific inputs being recommended. As it transpired, the recommended technologies were often found to be unadapted to the 'actual problems' of the small farms in the area.

In some developing countries animal traction was considered by governments to be an outmoded technology unworthy of research, and research emphasis was placed on tractor-based systems of cultivation. This was particularly common during the 1960s, but following the economic and technical failure of tractor-hire schemes, animal traction research programs were either started or revived in most developing countries during the 1970s. Where animal-draught was officially promoted, implements developed on research-stations were often found to be too heavy to be pulled by the local animals, too difficult to manoeuvre around tree-stumps in farmers' fields and inconvenient for transporting along farm paths. The wheeled toolcarriers developed, promoted and subsidised in Senegal, Tanzania, Uganda, The Gambia, India, Nigeria, Botswana and other countries between 1960 and 1985 were classic examples of technology that was developed, tested and 'perfected' on research stations but which proved unsuitable for the local farms. Despite extension promotion and price subsidies, farmers did not adopt these implements, and often opted for unsubsidised, simpler implements (Starkey 1988a). The attempted breeding and dissemination of exotic, large-framed draught animals proved equally inappropriate: the animals were appropriate to research station conditions, but they were not adapted to the nutritional and disease constraints of the surrounding villages (Starkey 1985).

It was therefore very much as a reaction to the problems experienced in applying the results of conventional 'on-station' research, that 'farming systems' research techniques were proposed and developed during the period 1975 to 1985.

Principles of FSR

Farming systems research starts from the premise that farmers are rational decision-makers, constrained by complex and interacting biological, technical, environmental and socioeconomic factors. Farm households (comprising individuals of different ages and genders) have multiple objectives and goals, some of which are likely to be conflicting. Farmers tend to seek solutions that optimise their use of available resources in the light of the prevailing constraints and conflicting interests (Poats et al. 1986).

Farming systems research involves the:

- **diagnosis** of needs, problems and constraints in farming systems;
- **design** of strategies to solve key constraints;
- **experimentation** with possible solutions; and
- **dissemination** of farmer-approved results to other farmers.

It is a central principle of farming systems research that the farmers and the farming community should be involved throughout the research process. The farmers, and where appropriate the farm families, should be actively involved in:

- the identification of the critical problems and constraints;
- the proposing of research programs to identify solution options;
- the selection of preferred options for testing;
- the choice of the criteria by which a technical option should be judged;
- the evaluation of the proposed solutions;
- the determination of any conclusions;
- the evaluation of the research program.

Farming systems research is a young subject, but it has already developed many of its own definitions, jargon and concepts. It is not possible in such a brief overview as this either to introduce the various specialised terms or to do justice to the many methodological principles and practices implicit in farming systems research. However, several authors have recently written in detail on the origins, principles and methodologies of farming systems research and people wishing to study the topic in depth and become familiar with the terms and acronyms employed are referred to such publications. Useful examples include those of IRRI (1985), FSSP (1986a,b), Poats et al. (1986), Zandstra (1987), Galt and Mathema (1987), Chambers (1988), Farrington (1988), Farrington and Martin (1988) and Starkey and Ndiamé (1988).

In other papers in These Proceedings, examples are given of how the FSR principles have been applied to animal traction research in Indonesia and elsewhere in Asia. These programs will not be reviewed in this paper, but brief mention can be made of the work of the Draught Animal Project (DAP) in Indonesia, to illustrate some of the methodological steps of FSR. Readers of the DAP Project Bulletin may have been aware that convenient sites for FSR animal traction research were selected that were broadly representative of different agroclimatic zones, technological and economic levels and farm characteristics (Santoso et al. 1987b). Sites selected included Padamulya and Tanjungwangi villages and after studying and describing the farming systems, some apparent constraints were diagnosed, and suggestions were made as to possible solutions or research initiatives to identify such solutions. Farmers were apparently concerned about animal health and were interested in alternative implement options. Researchers saw potential for improved use of feed resources and suggested harnessing, puddling and pack transport as areas of possible intervention (Sumanto et al. 1987; Santoso et al. 1987a). Follow-up actions and research were instigated, including the holding of a ploughing competition which allowed comparisons between cattle and buffaloes and single and paired animals and provided an opportunity for demonstrations of alternative technology options (Petheram et al. 1988). Parallel on-station research initiatives were designed to scientifically investigate some of the constraints identified in the villages and measurements were made on thermoregulation in buffaloes (Pietersen and Ffoulkes 1988) and the composition of forages (Zulbardi 1989). It is too early to appreciate what long-term impact these FSR studies will have, but it is already clear that the FSR approach has led to constructive collaboration between researchers and farmers.

FSR and Other Research Approaches

Farming systems research is not a dispassionate, academic research discipline, even though it may well involve rigorous scientific studies and profound social analyses. Instead FSR has been developed as part of an active agricultural development process. As a result FSR is often linked to extension programs and the term farming systems research and extension (FSR/E) is frequently used to describe the combined process (Poats et al. 1986). Where FSR principles are applied to development programs, the term farming systems development (FSD) may be used (Friedrich 1986). In this paper the term farming systems research (FSR) is used in its broad sense; even though the words extension and development do not appear in the title or acronym, it is assumed that, in most circumstances, FSR will directly or indirectly involve extension staff and 'development' programs.

It is important to stress that FSR is more of an approach than a discipline: people of any of the agricultural and social science disciplines may be involved in FSR. More importantly, FSR complements rather than replaces other research techniques. For example, the International Livestock Centre for Africa (ILCA) unequivocally states that it uses a farming systems approach in its research programs (ILCA 1988). This does not prevent it from undertaking laboratory research or from having controlled and replicated experiments on research stations, since ILCA intends that even in these cases the farmers' viewpoint should be central to the overall research process. ILCA's adoption of FSR should not be taken as implicit criticism of other research approaches; ILCA has simply chosen an FSR framework for its international research orientated towards development goals. Similarly, the fact that this paper is stressing the advantages of FSR should not be taken as implicit criticism of other approaches. As was discussed earlier, when farmers select a technology, by definition they must reject others. The rejected technology may be technically excellent and invaluable in other situations, but for that farmer, at that time, it is considered less appropriate than the alternatives. Similarly, the selection of FSR does not preclude the fact that other research approaches have validity, particularly in programs not closely orientated towards development.

Elements of FSR Methodology

Comprehensive Information Collection

Some of the earliest farming systems research started in Nigeria with large-scale data collection as a means to describe and analyse the local farming systems (Norman 1973). During the 1970s detailed socioeconomic surveys were widely undertaken; donors often required them as 'baselines' by which aid project interventions could be evaluated. Questionnaires were devised to allow quantifiable responses and enumerators were trained to put farmers' replies into predefined boxes to facilitate subsequent analysis. Samples were stratified and randomised following valid statistical procedures and wherever practicable data were fed into a computer. Today, in the late 1980s, there are unfortunately still many filing cabinets filled with completed questionnaires, waiting for that day when someone will have the time to analyse the data. On the other hand, there are also many that have been successfully analysed, and comprehensive tables and graphs produced. Nevertheless the data gathered and presented have not always contributed to real understanding of the farming systems. So much professional time has been taken up with handling information in predetermined categories, that there has been comparatively little time for reflection and interpretation. In extreme cases, researchers have found it difficult to see the farmers and farming systems for the data mountains.

In large-scale surveys, the data are only as reliable as the enumerators. It requires considerable discipline and modesty on the part of enumerators to record all the relevant responses of farmers without filtering out the 'difficult' answers that do not fit in with the preconceptions of the enumerator and the apparent objectives of the supervisors. In one animal traction and farming systems research program in Sierra Leone, it was concluded that the problems of reliable data collection and analysis of large-scale surveys were disproportionate to the quality of information that could be obtained by such techniques; it was decided to opt for survey techniques that would result in lower volumes of higher quality information (Allagnat 1984; Starkey 1988b).

Rapid Rural Appraisal

The response to problems of large-scale 'objective' surveys was the development of faster, simpler and less structured techniques for information-gathering. Instead of hiring many enumerators to ask predetermined and often fixed-response questions senior researchers would themselves go into villages and talk to farmers. Discussions that were (in principle) open-ended could lead to the researchers learning a great deal about the local farming systems. The genuine insights that were obtained by such techniques were seldom based on quantifiable data but were the result of private discussions and subsequent subjective analysis. This presented problems for it was difficult for researchers to report their findings to their colleagues and organisations on the basis of 'impressions' gained. The difficulty was overcome by using new terminology to give a straightforward technique professional acceptability. Talking to farmers was described as 'rapid rural appraisal' and became a formalised practice (Beebe 1985).

Rapid rural appraisal has been extremely useful, because it has encouraged researchers to visit farmers. It has also provided some legitimisation to publish potentially valuable but subjective opinions, 'gut-feelings' and genuine insights obtained by talking to farmers.

The main advantage, as well as the main disadvantage, of rapid rural appraisal is that the success of the technique depends to a large degree on the personality and preconceptions of the researcher(s). Send two researchers on rapid appraisal missions to the same area independently, and it is very likely that two very different conclusions may be reached; both may be entirely valid, but each will reflect the particular interests and experiences of the individual researchers and the farmers they have met. To avoid this one can make rapid rural appraisal into a very structured survey technique. Unfortunately as surveys become increasingly structured and analysable, there is a tendency to concentrate on the data at the expense of the insights.

Large-scale data collection, rapid rural appraisal and farmer discussions are not exclusive and many farming systems programs try to maintain a productive balance. In farming systems research in Indonesia, it has been noted that the quality and quantity of information obtained through farmer-completed diaries is dependent on good relationships and personal visits (Basuno and Perkins 1988).

Dealing with Complexity

One central theme of a farming systems approach to research is the complexity of farming systems, and the importance of interactions. The technical, biological and climatic interactions are daunting enough, but farming systems researchers have also to include the social, economic and cultural implications and ramifications of technical changes. For example, several research/development programs have been trying to monitor the very far-reaching effects of the introduction of animal-drawn carts (Mack 1984; Müller 1986; Sommer 1987; Huybens et al. 1987; Shetto and Kwiligwa 1988). Animal-drawn carts may facilitate the transport and conservation of crop residues, which in turn may affect animal condition at the beginning of the working period and thus the timeliness of cultivation. Carts may encourage farmers to apply compost, manure and fertilisers to fields, so increasing crop yields and residues. The extra operations and possible increases in yield may involve household members in extra work, perhaps to the detriment of other activities, such as schooling. The additional employment of the animals should lead to better animal training, so improving the efficiency and timeliness of cultivation operations, with possible social and economic implications. The hiring out of animal-drawn transport may increase household income, but may reduce both the interest in, and the labour available for, agricultural operations. Technical and economic success with transport may encourage other agricultural or nonagricultural innovations, while frustration with punctures and bearings may discourage further technological experimentation. It is therefore difficult to accurately monitor the *total impact* of the adoption of even a single farm cart.

The more one appreciates the complexity and ramifications of farming systems, the less possible it becomes to describe the systems, or measure single or simple parameters. Most farmers make their own subjective assessments of their technologies and results, and it has been suggested that researchers could make more use of such assessments (IRRI 1985; Starkey and Apetofia 1986). However most scientists want to be able to objectively assess and quantify aspects of the farming system. It would be a huge and impractical undertaking to try to objectively quantify all relevant aspects of complex farming systems; one has to compromise, be selective and make assumptions to simplify the complexity. This is one of the most difficult and critical aspects of farming systems methodology, for selectivity often involves subjectivity. By limiting information-gathering and analysis to limited areas of concern, researchers may miss out on crucial, but unexpected technical or social interactions.

Research on New Farming Systems

In India, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) had a specific 'farming systems research' program which attempted to develop improved farming systems based on animal power. For almost a decade from 1975 to 1985, an interdisciplinary team of ICRISAT scientists and economists developed and refined a system of farming based on broad-beds and furrows. Animal-drawn wheeled toolcarriers were used to construct and cultivate the broad-beds. The economists on the team claimed that the high cost of the wheeled toolcarriers could be rapidly recovered from the profits obtained by much higher yields (assuming that the soil conditions, management practices, technological inputs and crop yields of the small farms were comparable to those on the research station on which the technology was developed). However the technology package that had so painstakingly been developed over 10 years was rejected by village farmers after only 1 year of 'on-farm verification trials,' conducted at a very late stage in the program. As ICRISAT scientists themselves concluded, it was only when farmers belatedly participated in the research process that many of the real constraints in the local farming systems were understood (von Oppen et al. 1985; Monteith et al. 1988).

The animal traction element of the ICRISAT farming systems program provides us with a salutary and very recent example of the dangers of farming systems research studies that are limited to research station conditions. It also provides lessons on the reliance on optimistic assumptions. The ICRISAT 'farming systems program' involved a good multidisciplinary team of researchers, but it lacked one element now considered crucial to a real FSR approach since **farmers** were not closely involved until the final stages (Starkey 1988a).

Using a very different approach, an FSR program in Cameroon has also been trying to develop a new farming system based on animal traction and erosion control techniques. In this case, almost all of the work has been carried out 'on-farm' with men and women farmers actively involved in the research/development process (Rauch 1986; Zweier 1986; Wilfred 1989).

Research Involving 'Improved' Technologies

Many farming systems research programs develop, evaluate or promote the use of 'improved' technologies: 'improved' harnesses, implements, training techniques, feed supplements have been recommended instead of the 'traditional' alternatives. In Indonesia, at a recent ploughing competition 'improved' ploughs and harnesses were demonstrated (Petheram et al. 1988). In Mali, the Division de Recherches sur les Systemes de Production Rurale (DRSPR) has had a highly motivated multidisciplinary team of researchers working closely with farmers in a farming systems research/development program. Following a period of farming systems descriptions, diagnoses and problem identification, researchers from different disciplines felt able to suggest some possible improvements for the farming systems. Farmers were asked to compare 'improved' harnesses, training techniques, implements and forage cultivation systems with traditional practices (Sangaré et al. 1988). Impeccable farming systems research methodology seemed to be spoilt only by one small point: the use of this word 'improved' (Starkey 1988c). It was almost inevitable that anyone involved in the research, whether researcher, extension officer, enumerator or farmer would somehow be affected by the preconceived value-judgment of the word 'improved.' It would have been extremely difficult for anyone to conclude that the 'improved' alternative was less appropriate, once reputations had already been staked in the names.

Using FSR philosophy, farmers may be offered choices, but it is for **them** to determine which one is most appropriate for their farming systems. They should be allowed to make their own selection from a range of possible options. Researchers may discuss the advantages and disadvantages of the options, but they should avoid terminology that implies value judgment. As has been stressed, the most appropriate option may not be the one that is technically 'best.' Depending on the costs and relevant interactions, an 'increased' yield may, or may not, be an 'improved' yield. That which is rejected may be good in other circumstances, so that farmers' judgments as to what options are appropriate should not be taken as implicit criticisms of the rejected choices (they may or may not be). In general, researchers would do well to avoid using terms that imply value judgments whenever there are more neutral descriptors available.

Imperfect Farmers

One of the key techniques of farming systems researchers is to try to see things through farmers' eyes and to understand the complexity of farmers' judgments. If farmers reject or accept a technology it is probably for a very good reason, perhaps not clearly apparent to those only thinking in terms of technical efficiency. Farmers have to consider social and economic costs and benefits, in their technical judgments. The old view of small farmers being irrational and bound by 'traditional inefficiencies' has tended to be replaced by the new perception that farmers endeavour to efficiently optimise their limited resources. However farmers throughout the world are influenced (positively or negatively) by fashions, prestige and symbols of status. Some farmers will adopt technologies simply because they are new and innovative, while others will reject them for precisely the same reason. The colour of an animal or an implement can have a decisive influence on whether it is accepted or rejected, even though this is unlikely to affect performance. Thus farmers are certainly not infallible in their technical judgments, and they can make decisions that may be 'right' for them, but which outsiders would consider as 'wrong.'

During the 1960s and 1970s many extension personnel considered farmers to be ignorant and in need of proper guidance. One animal traction extension manual of the 1970s started with the words "The average Ugandan farmer has a small farm; he has low income, and little farm knowledge know-how" (Akou 1975). In more recent years FSR philosophy has helped to overcome such attitudes, for some seemingly illogical practices start to appear very sensible when viewed through the eyes of a farmer surrounded by diverse social, economic and environmental constraints. For example the apparently time-consuming, tiring and wasteful practice of trying to cultivate with poorly trained animals was logically explained by one farmer in The Gambia. He knew how to train animals but considered that well-trained oxen were at risk from cattle thieves, while wilder oxen could not be abducted. Donkeys were well-trained because no-one ate donkey meat and so donkeys could be allowed to wander freely in the bush without the risk of theft (Starkey 1987). According to the attitudes of the 1970s, if farmers had badly-trained animals, they should simply be taught better training techniques. According to FSR processes, the situation should be more completely understood from talking to farmers. Following this one might investigate, with farmers, whether the risk of cattle theft could be realistically averted. One might also consider, with the farmers, whether donkey cultivation could become a realistic alternative to using poorly trained oxen, and the implications of this for equipment design, harnessing, animal nutrition and the household economy.

Although such examples of very logical 'poor practices' can be cited, FSR has still not come up with answers to the problem of what to do when farmers are actually 'wrong.' For people involved in animal traction research, animal welfare may be one such dilemma. Animals may be expected to work hard, and they may have to be encouraged or admonished, but causing **unnecessary** suffering to animals is (in the author's opinion) 'wrong.' This is a value judgment that many farmers do not seem to accept, and one can certainly *try* to see things through their eyes. One (French) farmer recently admitted he beat his animals unnecessarily in order to relieve his own frustrations, but, he argued, at least he did not beat his wife. While researchers can be very understanding and sensitive to the background, culture, experience, economic constraints and problems of farmers, it does not detract from the premise that it is not acceptable to condone actual cruelty to animals. Everyone closely involved with animal traction will have seen examples of injuries caused by poor harnessing, improper use of implements, excessive use of sticks or whips and even gratuitous violence. FSR may well lead to the conclusion that, from the point of view of the farmer, these are not limiting factors worthy of change. Nevertheless, scientists may use FSR principles to gain understanding of the underlying causes, and to identify potential technical or administrative solutions that are socially and economically appropriate.

Need for Observable Results

A major strength of farming systems research is that it greatly increases the understanding that researchers have of the local farms and farmers. The associated problem is that this is often **all** there is to show for the research. For example, FSR may well reveal that limited market access and low producer prices are crucial constraints to smallholder farmers (this is indeed a common situation in Africa, particularly where urban food prices are kept low through the distribution of imported food aid). In such circumstances, animal draught power and implement design may be important, but not actually primary limiting factors so that it may be difficult to see how modifications to implements, harnessing systems or the draught animals could make a significant impact. For example, following field visits and discussions with farmers, participants at an animal traction FSR workshop in Sierra Leone highlighted the importance of general economic and infrastructural constraints to the development of animal traction technology; in one village the lack of a bridge was considered a crucial constraint that would limit animal traction adoption (Starkey and Ndiamé 1988). In this case a major constraint to animal traction has been identified that is not really researchable by specialists in animal traction. This might well be dismissed as being exceptional, but it may well be 'typical' of the various 'exceptional' constraints found in the villages of the area.

Using 'on-station' research techniques one can avoid such problems of nonresearchable constraints. At the same time by carrying out on-station research one has something to show visiting directors of research, politicians, diplomats and aid donor representatives, the very people who will influence future budgets and career promotion. In a recent case study from Sierra Leone, it was concluded that the major benefits of the national animal traction program had come as a result of the FSR work with farmers in the villages. However it was also noted that the FSR had only been funded because visiting national and international 'decision-makers' had been impressed by the (unrealistic) on-station trials and demonstrations. It was concluded that had the project started with an FSR philosophy, it would have omitted most of the impressive (but in retrospect largely irrelevant) on-station work; had this been the case, the project would probably have been terminated early, due to lack of funds and visible results (Starkey 1988b). FSR philosophy can be an invaluable research tool, but unless it is combined with pragmatism to obtain support and recognition, its attraction may well prove economically fatal to research programs.

Implications: Realism in Future Research Programs

From a review of many animal traction research and development programs, it is evident that those programs that had little impact often lacked the farmers' vision of reality. Farmers (unlike researchers developing models) cannot remove the real constraints by simply assuming they do not exist! Farmers have aspirations, but they do not prevent them from being realistic and pragmatic. Programs, on the other hand, have often failed to clearly distinguish between the *present realities* of the actual farming systems and their *aspirations* for future improvements. For example if farmers' fields have tree roots in them, all cultivation implements intended for such farming systems should be able to cultivate in the presence of roots. Naturally farming systems are constantly changing so that the addition of a new item of equipment may lead to changes (large or small) in the whole system. Thus the availability of an implement that can only work in root-free conditions *may* cause farmers to remove the stumps from their fields. It may, on the other hand, lead to the rejection of the implement as inappropriate to the actual conditions. Thus clear distinctions must be made early in a research program between the *realities* of existing farming systems and any *assumptions* relating to prerequisite future changes that have been made. Common assumptions relating to animal traction equipment use have included:

- changes in the timing and duration of operations;
- increases in yields and profitability; and
- improvements in the availability of technical services (such as animal health or implement repair services).

In general, optimistic assumptions should be avoided or kept to a minimum: wherever possible innovative animal traction technologies should be selected that can be used within the *actual conditions prevailing*. This may mean that animal traction programs may find it more beneficial to anticipate small but progressive changes in farmer demands for techniques and equipment rather than to promote technological leaps.

Realism is also required in assessing the available power of the animals. One of the most common mistakes made by animal traction programs in recent years has been to seriously overestimate (or overlook) the draught capabilities of the farmers' animals. Many equipment designs produced by engineers on research stations have been rejected by farmers as 'too heavy' for their animals. *If animals are normally in poor condition* at the time an operation is required then it should seem quite evident that *equipment must be capable of being pulled by animals in poor condition*. There is little to be gained from promoting heavy equipment developed and tested with large and well-fed animals, if similar beasts do not exist in the local farming systems.

The realistic approach of FSR does not preclude trying to improve the condition of the animals at the same time as equipment is being promoted. What is essential, however, is to carefully distinguish between present realities and optimistic assumptions. A 'package deal' may well be envisaged in which the use of heavy equipment is directly linked to improved animal nutrition, *provided* it is understood by all concerned that such equipment is *not* designed for the existing farming system. In such a case the very ambitious nature of the objectives should be clearly understood since any 'stronger animals' policy will have a very much wider scope than normal equipment-package credit-programs. The promotion of 'heavy' equipment necessitates successfully tackling one of the most difficult animal traction problems, that of finding a *realistic* and *economically acceptable* way of improving animal condition in normal village circumstances. Until proven, realistic and acceptable methods of improving draught power are available, animal traction equipment should be suited to the strength of existing animals.

Realism is particularly important when assessing the impact of highly variable components of farming systems, such as the weather. There is a natural tendency to design technologies for 'average' conditions, yet FSR makes it clear that, in reality, *there is no such thing as an average year.* Most years are exceptional in some ways, being particularly dry, wet, late, early, hot, cold, calm, stormy, or with greater/fewer than normal weeds, insects, fires, social obligations or political upheavals. If this should seem obvious and self-evident, it may be illuminating to read (or reread) the recent annual reports of current research and development programs working with animal traction. It has been frequently concluded that the animal traction technology on trial (on-station or in farmers' fields) was basically excellent, but unfortunately it did not do well *that year* because of 'exceptional circumstances.' Seldom were such constraints major, once-in-a-generation catastrophes, and most were the normal 'exceptional conditions' that a farmer must survive each year. Again it is a question of realism: animal traction technologies must be applicable to the wide range of physical and social conditions that regularly occur in the relevant farming systems.

Realism is also important when assessments are made of the environmental and socioeconomic impact of animal traction technology. In the past researchers tended to pose questions only to male farmers who were heads of household, and tended to overlook possible conflicts of interest between people of different age, gender and social status. With FSR it is important to solicit the views of many different members of the community likely to be affected by technological changes. In cases involving grazing rights or environmental degradation, it may be that the views of the community will differ markedly from those of individual farmers. In cases involving new animal traction technologies, the farmers, their families and their communities may ascribe different levels of significance to the operation(s) involved. It is usually most important to understand precisely who undertakes the various operations (male or female; child, adult or elderly; farm household, community labour or hired worker), the time taken to perform the operations and whether they are undertaken at times when labour is plentiful or scarce. If the objective is to use animal power to replace human power, it is important to determine whether there would be a beneficial or detrimental shift in the category of labour or the time of operation. With an assessment of the value of the operation, it should be possible to gauge an affordable cost. Again realism is essential and optimistic assumptions should be avoided: far too many programs that ended as disappointments had judged that farmers could have afforded high-cost implements *assuming* that labour productivity, cultivated areas and yields had increased dramatically. FSR studies have often shown that in the early years of animal traction adoption, farm cash-flows can be negative and that crop yields per unit area may go down, as farms become more extensive (Barrett et al. 1982; Reddy 1988; Francis 1988).

Conclusions

It should be apparent that farming systems research is not a solution nor an end in itself. Rather it represents an invaluable framework for research/development programs. By involving the farmer at all stages in research programs, the risk of making unrealistic assumptions about the farming systems is greatly reduced. In the past 30 years, such unrealistic assumptions have resulted in a vast waste of research time.

The adoption of FSR practices and methodologies does not mean that agricultural research stations have no future. However with FSR the farmers' viewpoint can be considered even on a research station, and it has been recommended that on-station research should always be closely linked with on-farm trials (Starkey and Ndiamé 1988).

It has been suggested that the 'technological shelf' of animal traction is broad and full of options (Gifford 1988). Researchers have access to a vast amount of information from around the world on the numerous technological options available, and the manner and success with which they have been employed. Farmers are not aware of all these options, but they do have practical understanding of the problems of farming in the prevailing conditions. Farming systems research essentially combines the researchers' comparative advantage of worldwide and technical knowledge with the farmers' comparative advantage in practical experience and fine-tuning decision-making. The researcher can offer the farmers scope for rapid evolution of farming systems, by allowing selection and rejection from a much greater range of variation than would otherwise be possible. The farmer offers the researcher not only a complex and valid rationale on which to base experimental procedures, measurements, selection and evaluation criteria but also a strong sense of realism, to ensure that research work remains closely relevant to its objectives.

The strength of farming systems research lies in its open-ended structure and commonsense approach. Having 'rediscovered' farmers, farming systems researchers occasionally appear to be in danger of losing them again among clouds of jargon and a soup of acronyms. In my opinion, it matters relatively little whether farming systems terminology survives, as long as the overall philosophy remains. When all researchers regard it as entirely natural that farmers are closely involved in research, people may well wonder what FSR was all about. Only the examples of unproductive research of the past years will be there to remind them.

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Descriptive Research on Draught Animal Power Systems

Santoso and Sumanto*

Abstract

The description (or diagnosis) of farming systems research (FSR) sites can involve a wide range of methods, from formal surveys (of farm management) and long-term monitoring (e.g. of liveweight, inputs and income) to rapid appraisal methods (e.g. collecting data from key individuals) and special studies of constraint topics (e.g. animal work rates, reproductive performance, health, implement use).

As the aim in 'description' is to accurately define the main constraints to system improvement, as efficiently as possible, the choice and development of appropriate methods can be critical to the progress of FSR on DAP systems.

Descriptive data on DAP farming systems is often poorly presented in the literature. As FSR depends upon specialists from many disciplines being involved and having a sound understanding of the farming system, presentation should be as clear and as 'diagrammatic' as possible.

Some research methods developed for description of DAP systems in Indonesia are outlined, and a list of headings is suggested for an agroeconomic profile of an FSR site in Java, where improvement of DAP is the focus of research. Several examples of figures summarising socioeconomic and biological data from profiles of DAP systems research sites are presented (mainly from Indonesia).

The description of FSR sites is a continuous process, for which valuable information is collected even after the stage of farm trials is commenced. Some of the most important information (e.g. on farmers' attitudes to ideas for change) can only come from testing ideas on farms. Sound descriptive research of DAP systems therefore depends not only on the involvement of specialists, but also on the participation and trust of farmers, in diagnosing problems.

Introduction

THIS paper is a review of research on the description (or diagnosis) of farming systems, with particular reference to draught animal power (DAP). Although it is accepted that different livestock/ farming systems will require different methods and types of descriptive data, most of the examples are taken from Indonesia, as a framework for general discussion of this topic.

The aim and end-point of descriptive research in farming systems research (FSR) is the *diagnosis of constraints* to improving the farming system (Collinson 1984). Hence, sound description is essential to all the later stages of the FSR procedure (Fig. 1).

In practice, the descriptive FSR is very closely linked with other stages of research, and description is a continuous process, and interactive with other research phases. The FSR phases of system development and testing are discussed by others (These Proceedings).

Methods

Data for description of existing DAP farming systems have been collected in FSR mainly by the following:

* Balai Penelitian Ternak, Bogor, Indonesia.

Table 1. Headings for an agroeconomic profile of a DAP systems site.

Background/History/Geography
- Climate
- Land use

Population
- Population, age structure, occupations (education)
- Land ownership/tenure
- Livestock ownership

Agriculture
- Cropping patterns, crop yields, profitability
- Tillage practices and sources (DAs, tractors, etc.)
- Land preparation patterns

Draught Animal Rearing
- Proportions of farmers rearing/using DAs
- No. of DAs reared/farm (+ unit area)
- Village DA population/density, herd structure (age/sex)
- Feeding management (general)

DA Use
- DA use — rental, own land, etc. Days work/season (year)
- Different operations/tillage/transport, etc.
- Male/female use and pairs/singles use

Feeding Management of DAs
- Source, patterns, labour use, planting

Health and Breeding Management of DAs
- Mating practices, farmer knowledge
- Calving rates, bull availability

Rearer Opinions About Rearing
- Main work periods/demands for rental
- Main problems/feeding difficulties + times

Nonrearer Opinion of DAs
- Main reasons for not rearing/other power sources
- Desire to own DAs

Main Farmer Domains
- Productivity + income per domain
- Target groups of farmers

Economics of DA Rearing
- Income from DA enterprise/work/sales/rental
- On-farm and off-farm income/markets

Main Constraints to Improving DAP System

Ideas for Improvement

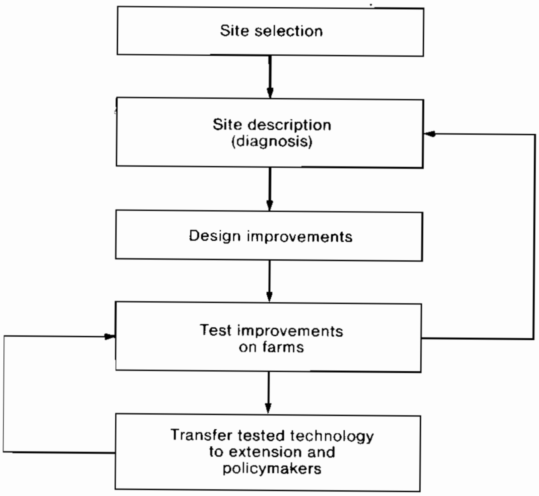

Fig. 1. A classical farming systems research procedure.

- simplification of secondary data, e.g. mapping of livestock densities and land use types (Perkins et al. 1986);
- rapid appraisal methods (Beebe 1985), e.g. rapid farmer surveys, interviews with key farmer groups;
- formal surveys, e.g. of land and livestock ownership and age–sex distribution of draught animals (Santoso et al. 1987);
- long-term monitoring, e.g. of liveweight changes, stock transactions, reproductive status (Sumanto et al. 1987);
- special studies of constraint-oriented topics, e.g. feeding practices, forage availability, animal health, DAP implement use, work rates, reproductive performance, labour use (e.g. Soehadi 1987; Usri 1988); and
- farm trials to gauge farmers' responses to new ideas or technologies.

In FSR, there are often many different ways of obtaining the same information, e.g. the number of *days that animals work per year* may be estimated from farmer recall data, from rapid surveys, by monthly visits over 12 months, or by daily data records completed by farmers. Rapid appraisal methods have been developed for estimating various important variables in DAP systems. However, the cost and accuracy of these must always be compared with that of more intensive methods of data collection.

Although much of the initial data needed in description of DAP systems can be obtained by rapid methods, there are some types of information that can only be assessed through long-term and close farmer contact. Close farmer contact and the respect of farmers is essential for the later stages of FSR, when accurate data and honest opinions are needed from farmers on matters concerning possibilities for changing the system.

The essence of data collection in FSR seems to be to devise simple and time-effective methods of

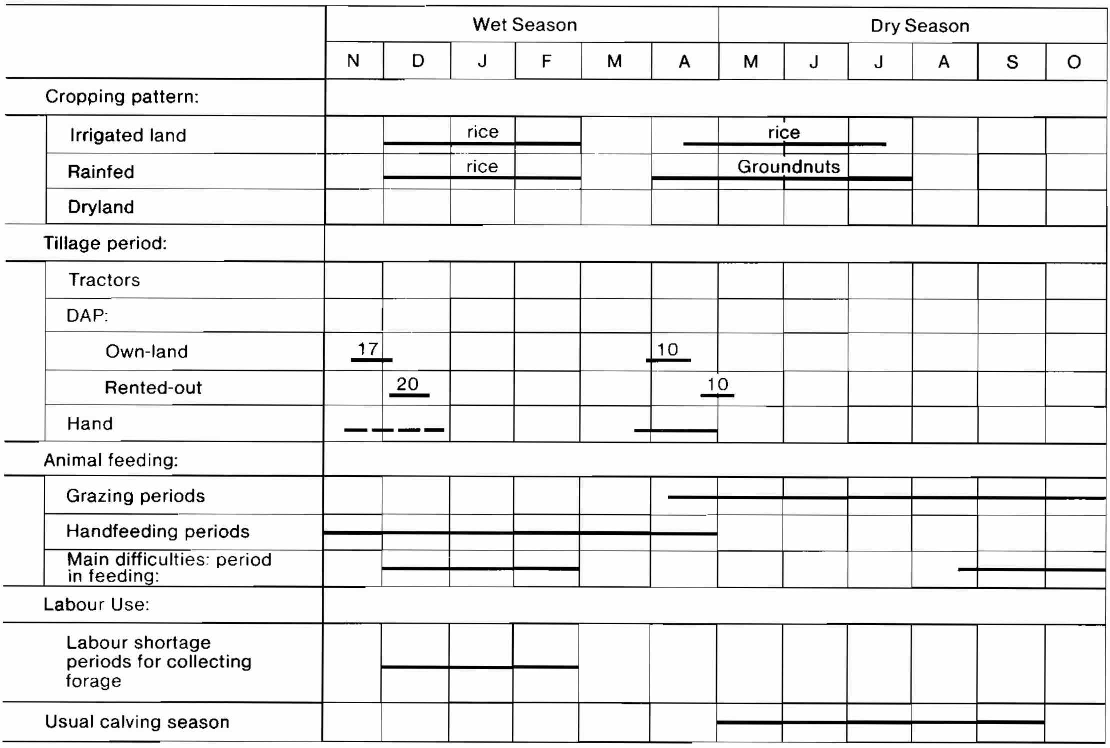

Fig. 2. Example page from farmer questionnaire.

gathering key data from farmers. One example of a method developed in Java is illustrated in Fig. 2, where information on a range of topics is collected from each farmer about crop rotation, DA use, labour shortages, DA feeding patterns, and main feeding problem periods on a calendar basis. The advantages of using such a pictorial questionnaire method are: ease of recording; drawing lines is less inhibiting for the farmer than writing; much related information can be shown on the same page; and the information can be easily quantified if required.

An example of quantitative data taken from such a pictorial (or graphic) questionnaire is shown in Fig. 3. Many other examples of methods developed for rapid assessment exist, although these are seldom shown in the literature.

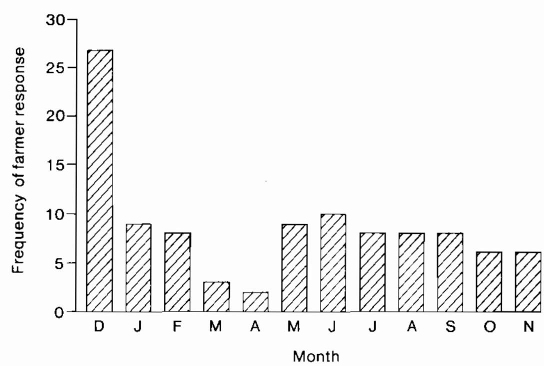

Fig. 3. Farmer opinion on most difficult periods in obtaining feed.

Profiles of DAP Systems

In FSR, the research sites (usually villages) are chosen to represent important farming systems, of which draught animals are a component, in the case of DAP-oriented research.

The task of description involves not only the collection and analysis of data about each research site, but presenting these data in a useful and digestible way. In the ACIAR/DAP Project (and other FSR programs), site descriptions are written in the form of an agroeconomic profile (e.g. Santoso et al. 1987; Sumanto et al. 1987). These profiles serve as a reference for the multidisciplinary team involved in the FSR process (i.e. scientists, administrators, extension workers and other specialists). They also serve as a benchmark for future studies. The emphasis in developing agroeconomic profiles is to collect only relevant data and to present this as clearly as possible, using simple diagrams and tables (Bernsten et al. 1980).

Much of the data collected in describing the role of draught animals in farming systems remains either unprocessed or poorly presented. There are some useful descriptions of DAP farming systems (e.g. Falvey 1977; Goe 1987), but there has been a tendency for descriptions to be: (a) too general to be of value in designing improvements to systems, or (b) too specifically related to a particular discipline (e.g. work output, crop inputs or economics) to give a useful picture of the whole system. To be useful in FSR, profiles of research sites must cover the key socioeconomic as well as biological information. An example of an outline of an agroeconomic profile for an FSR site is shown in Table 1, which shows only the main headings of each topic covered (Sumanto 1989).

Figures 4–12 and Tables 2–8 are presented as examples of information for description of DAP systems. Data for profiles of farming systems are intended to be as simple and digestible as possible, so that these may be easily understood by the people from various disciplines who must invariably be involved in the FSR process.

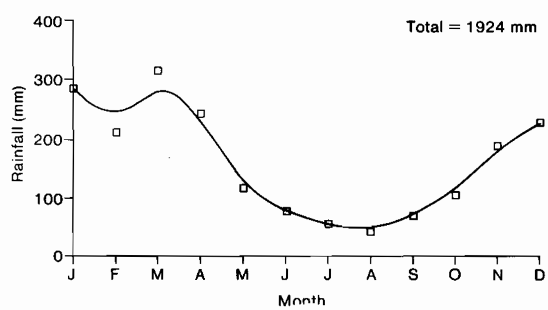

Fig. 4. Average monthly rainfall, Padamulya (1969–86).

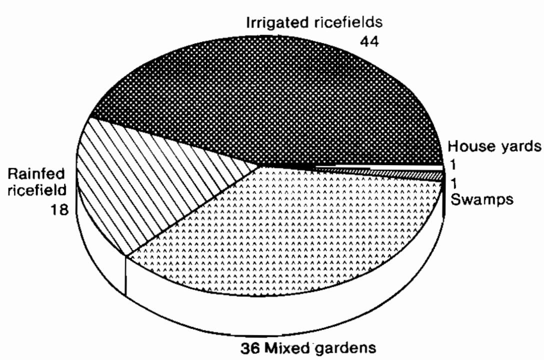

Fig. 5. Land use in Padamulya village, West Java.

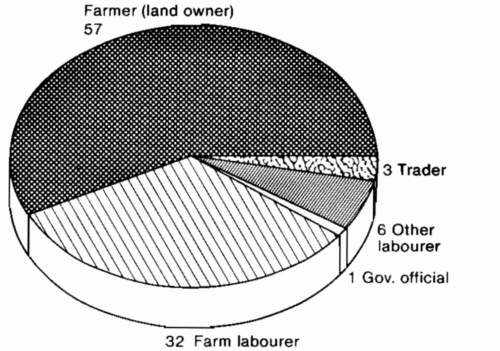

Fig. 6. Main occupation of working residents of Padamulya.

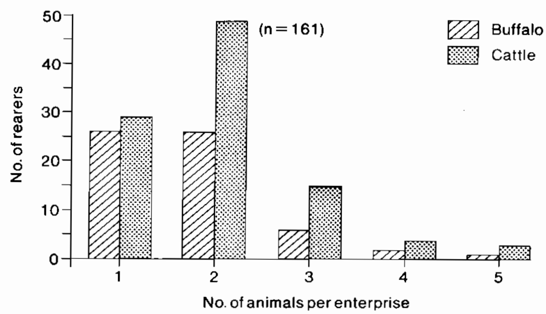

Fig. 7. Size of large ruminant enterprises.

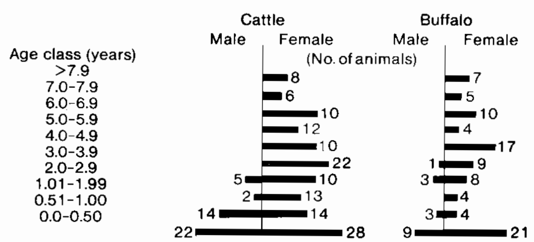

Fig. 8. Age/sex structure of large ruminants.

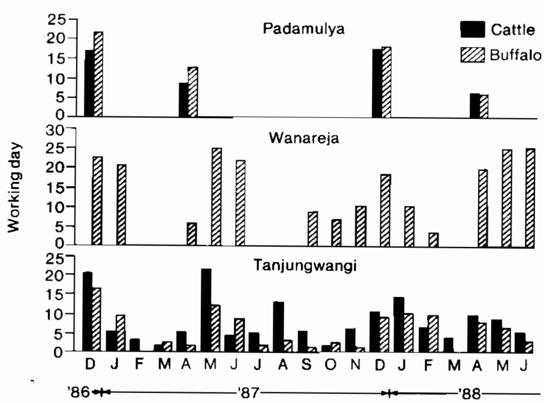

Fig. 9. Average days animals worked per month in three villages, West Java.

Table 2. Pattern of draught animal use in land preparation ($n = 40$).

Farmers' usual pattern of operations involving animals in land preparation	First wet season planting (Nov–Dec)	Second wet season planting (Apr–May)	Dry season planting (July–Aug)
		(Percentage of all rearers working)	
Plough 2×; level 2×	8	3	–
Plough 2×; level 1×	18	8	–
Plough 1×; level 2×	3	3	–
Plough 1×; level 1×	60	35	–
Level 2×	–	5	–
Level 1×	–	5	–

Table 3. Main problems faced by rearers ($n = 40$).

Problems	%
• Shortage of feed	70
• Shortage of communal area	60
• Shortage of labour for grazing and hand-feeding	25
• Animal health	15
• Buffalo bulls	15
• Shortage of capital	10
• Pens areas	5

Table 5. Farmer's income from different work.

Source	Rearers	Nonrearers
	Rp/household	
• Farm	847.000	758.000
• Labour in agricultural sector	170.000	65.000
• Labour in nonagricultural sector	91.000	923.000[a]
• Total	1108.000	1746.000

Source: Perkins and Basuno (1989).

[a] This figure seems excessively high and is being investigated.

Table 4. Nonrearers' desire to rear draught animals in Padamulya village ($n = 40$).

Farmers' response	%
• Not in favour	13
• In favour (79)	
— Cattle	38
— Buffalo	41
• No response	8

* Main problems: lack of capital and feed.

Table 6. Main constraints to improvement of DAP in Subang.

- Shortage of basal feedstuff and labour for feeding animals at certain times
- Shortage of high quality feed for certain periods
- Low ploughing rate/efficiency of pairs of DAs, compared to singles
- lack of advice/remedies for animal health problems
- Lack of advice for farmers on DAP
- Lack of capital for farmer for purchase of DAs
- Shortage of buffalo bulls
- Poor farmer knowledge of principles of reproduction

Table 7. Example of constraints and ideas for improvement.

Constraint	Ideas for Improvement	Priority + action: Stat. trials	Farm trials	Notify policymakers
• Shortage of basal feedstuff and labour for feeding animals at certain times	• Plant forages;	–	1	–
	• Preserve rice straw;	1	1	–
	• Use animals to cart straw/forage — carts, sledges, packs	–	2	–
• Low ploughing rate of pairs of DAs	• Improve ploughs	–	1	–
	• Increase work periods of buffalo (wet sacks)	–	2	–
	• Improve harnesses	–	2	–
• Shortage of buffalo bulls	• Approved bull schemes (farmers subsidised to keep bull in village)	–	2	1
• Lack of advice for farmers on DAP	• Improved extension	–	–	1
• Poor farmer knowledge of principles of reproduction	• Farmer training	–	–	1

Table 8. Sample data collected in description of village sites, and sources of data.

Methods	Data	Source
• Collect secondary data	• Rainfall	1
	• Land use	1,2
	• Livestock population, etc.	1
• Initial village visit	• Gen. topography	3
	• Village map	4
	• Land use (per hamlet), etc.	4
• Village trips/walks	• Village layout	3
	• Main soil type	5,7,9
	• Main forage + feed, etc.	5,7,9
• Census of all rearers	• Land use per family	6
	• LRs distribution	7
• Monitoring livestock	• Stock transaction	7
	• Feeding practice	7
	• Problems in rearing LRs	6
	• Liveweight, etc.	8
• Special studies	• Animal health — problems	8,9
	• Work activities	7
	• Force of LRs	8
	• Characteristic of harness + implement	8

Symbols:
1. Stat. office at Subang
2. Agric. office at Subang
3. Observations + discussions
4. Village records
5. Interviews (key informants)
6. Farmer interviews
7. Observations + interviews
8. Records + observations
9. Samples collected

LR = Large Ruminant.

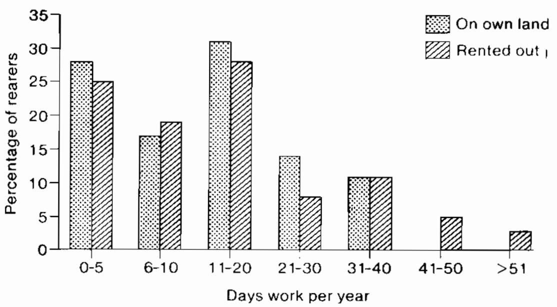

Fig. 10. Days worked on own land rice crop and rented out (cattle and buffalo rearers combined; n = 36).

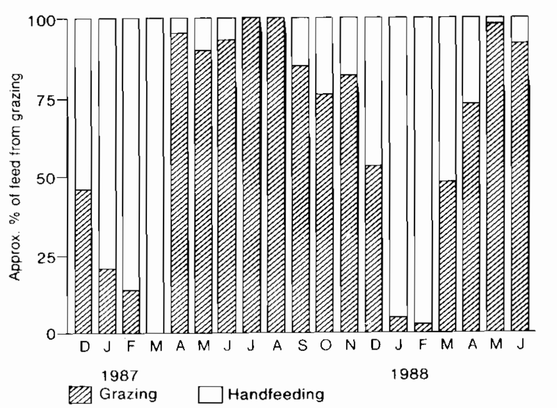

Fig. 11. Proportion of feed from grazing (and handfeeding) for cattle in Padamulya, West Java.

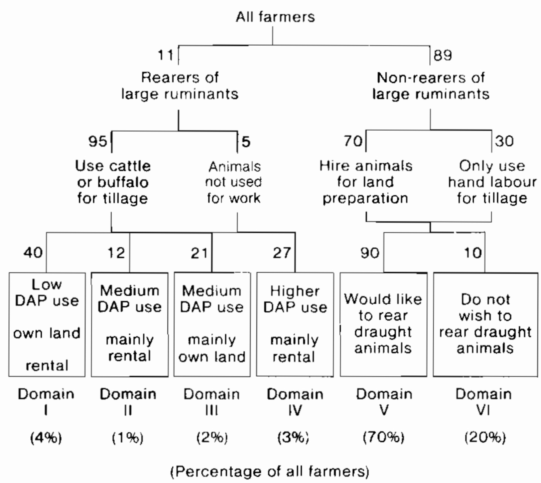

Fig. 12. Farmer recommendation domains in Subang, West Java.

Conclusions

In this review we have tried to cover the topic of what records, measurements and other data are needed to describe a farming system, with a view to improving the DAP subsystem. As the objective in FSR is improvement to the system which increases the income (or other benefits) to the farmer, it is necessary to understand the farmers' economic situation, current practices and values, as well as the biological features of his/her farming system. In draught animal rearing, data on labour use may be important, as savings in labour through alternative practices may (or may not) benefit the family. One study of a site in Java (Perkins and Basuno 1989) showed that nonrearers of DAs were able to earn much higher income from off-farm labour than rearers, who were tied to herding their animals throughout the year.

Because farmer opinions and attitudes to new practices cannot be easily determined by other means, it is desirable to undertake simple trials on farms at an early stage in FSR (e.g. before the long-term monitoring studies are complete). Farm trials of 'best-bet' technology early in the FSR process can also be invaluable in improving the high level of farmer/scientist contact needed in accurate diagnosis of problems and in on-farm testing.

An important task in description of DAP systems is to define the main farmer domains (e.g. DA owners, DA renters, nonrearers), and the proportions of each in the farming population (e.g. Siriluk et al. 1987). Without this information, it is difficult to design research programs to benefit the most important farmer groups, or to decide on priorities for research.

The estimation of income from DA enterprises needs to follow the definition of the main farmer domains, and only after this is it necessary to measure the working performance of animals used in each domain.

In addition to estimating animal work output, it is essential to measure other forms of animal production and income to the farmer, e.g. calving and growth rates. The value placed by farmers on other assets in rearing livestock, such as family security, capital investment and status, must also be determined if system improvements are to be designed that are acceptable.

In general, rearers of DAs usually use existing animal feed and other resources quite efficiently. It is necessary to have a good knowledge of existing feeds and feeding practices and animal productivity before our knowledge of the feeding and physiology of animals for work can be applied. However, much can be gained by trials of ideas on improved feeding practices, implements or other proposed improvements, early in the FSR process. Without such on-farm testing, the assessment of farmer attitudes to change (an essential part of diagnosis) cannot be completed.

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Farm Trials of Proposed Improvements to Draught Animal Power Systems: A Review

R.J. Petheram*, Sumanto and C. Liem†**

Abstract

The conduct of farm trials is a major part of farming systems research (FSR). The main documentation of farm trials, generally, and on-farm trials of DAP technology, is found in the FSR literature and in recent literature on farmer participatory research. Because of difficulties in the design of experiments on farms, and in publishing results, most agricultural scientists have preferred to work on research stations. However, because of the complexities of the human/animal/soil/implement interactions of DAP systems, it is essential to test ideas for system improvement on farms, as these conditions can seldom be duplicated on research stations.

Types of farm trials reported in DAP research vary widely with discipline (e.g. engineering, nutrition, agronomy) and aims in research. Because of small farm size and animal numbers, and high variation, farm trials must inevitably be simple and small. Farmer opinion is often a more valuable criterion for evaluation of a technology than statistical differences in terms of crop yield or animal performance.

Recommendations are made for better documentation of methods and results of farm trials (including failures), and for greater involvement of specialists and extension agents in farm trials. The most successful farm trials of DAP technology reported tend to be those in which farmer participation in research is actively encouraged. The development and testing of methods of communicating ideas can be an important adjunct to the main aims in farm trials — i.e. of testing technology in the eyes of target farmers.

Farm trials are dependent on accurate diagnosis of system constraints and careful specification of target farmer domains. A balance of descriptive research and farm trials is required in FSR, and these activities should be closely linked to station research and extension agencies.

Introduction

THE various research phases in a classical farming systems approach are well known. In this paper, it is necessary, first, to define terminology related to 'farm trials' and to indicate the place of various on-farm activities in a farming systems research procedure. A range of farm trials that have been conducted in the field of draught animal power (DAP) is outlined, and comments offered on the value and problems of this mode of research.

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Farm trials are taken here to mean research activities on farms, aimed at studying, testing, adapting or comparing technologies for their suitability to the needs of farmers. Synonymous terms are *on-farm trials*, *farm testing* or *adaptive research on farms*. These terms, however, should be distinguished from another common FSR term, *on-farm research*, which includes farm trials, as well as all descriptive research conducted on farms, such as farm surveys, studies of crop or livestock productivity and the collection of economic data on farms.

A classical FSR procedure is shown in Fig. 1(a), as has been developed and used (in more or less standard form) by various FSR programs throughout the tropical world (e.g. Harwood 1979;

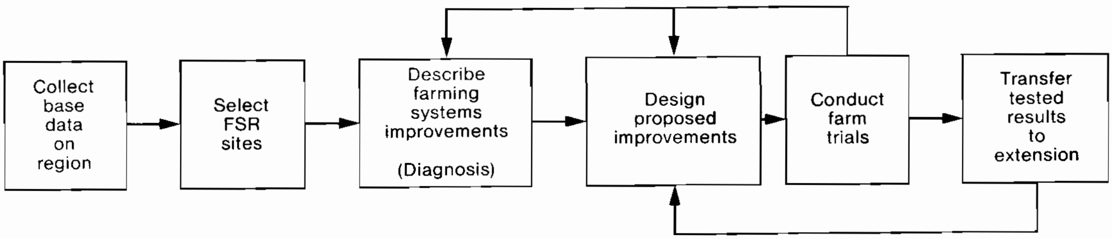

Fig. 1(a). A classical farming systems research (FSR) procedure.

Fig. 1(b). An FSR procedure, bogged down in description or design of improvements.

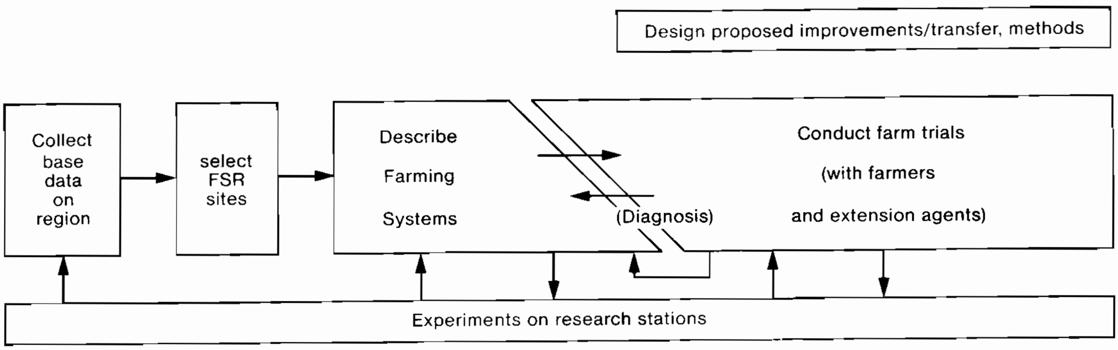

Fig. 1(c). A modern FSR procedure, showing emphasis and place of farm trials.

Zandstra et al. 1981; Lagerman 1982; Dillon and Anderson 1984; Norman and Collinson 1985). The literature indicates that different FSR programs tend to emphasise different parts of this classical procedure.

A past criticism of FSR has been that it has often overstressed the *description* of systems, without moving on (soon enough) to the work of *farm trials* to test possible improvements (Chambers 1980; Simmonds 1984), as depicted in Fig. 1(b). Achieving a realistic balance between description and testing on farms is an important element in the management of FSR.

A modern FSR approach is shown in Fig. 1(c), in which farm trials begin early and become increasingly important in the research procedure. This reflects the high value placed in recent FSR literature on farm trials as a *diagnostic tool*, as a means of encouraging *farmer participation* in research and of *assessing farmer attitudes* to ideas for changes to their system (e.g. Johnson and Clarr 1986; Collinson 1987; Farrington 1988). In this FSR procedure (Fig. 1c), descriptive research and farm trials are very interdependent; description leads to ideas for testing, and farm trials, in turn, provide feedback for description and diagnosis of system constraints.

Farm Trials and Experimentation on Research Stations

The concept of farm trials is not new, or exclusive to FSR, but has formed part of the traditional research/extension model in many countries. However, in FSR, farm trials are claimed to have special value in the way that they involve research scientists and farmers (with extension agents) in testing ideas on farms (Johnson and Clarr 1986).

Experimentation in FSR has been discussed in Winkelmann and Moscardi (1981), Collinson (1982), Nygaard (1982), Mueller (1983), CIMMYT (1982), ICRISAT (1983) and others, mainly with reference to crop components of systems. A major controversy has concerned the value and place of testing on research stations versus farms, or in vitro versus in vivo trials (Anderson and Hardaker 1979).

Whiteman (1978) remarked that 'researchers need courage to expose themselves to the uncontrolled conditions of farmers' fields,' while Bernsten (1982) and De Boer (1983) claimed that conducting trials on farmers' animals is even more daunting than on crops. The main difficulties in conducting farm trials involving draught animals (DAs) arise from the limited size of most DA enterprises, the extreme variation between farms and the high demand placed by trials on family resources and researcher labour (Nordblom et al. 1985; Petheram and Basuno 1985). These conditions seriously limit the degree of experimental control possible, and hence the use that can be made of farm trials as experiments in the conventional sense.

For these and other reasons, most scientists working in DAP (and other agricultural fields) have concentrated their efforts towards the 'basic science' end of the research/extension continuum. In some areas of DAP research (e.g. that of implement design), there has been a preponderance of work in the mode of technology development, although this has been mainly on research stations (Starkey 1988).

While technology design in FSR is often dependent on data from research stations and laboratories, there are numerous reasons why results of technology development on stations may not be applicable on small-scale farms, e.g. availability of labour, capital, and other inputs, limited stock or land ownership, social acceptability (Partenheimer 1983; Richards 1985). This is particularly the case in secondary components of farming systems (Baker et al. 1988), such as DAP enterprises, where the complex relationships between operator, animal, soil and crop are difficult to simulate on research stations.

Types of Farm Trials in DAP Research

Reports of trials on farms may be grouped according to their major aim and to the discipline under which they fall (e.g. engineering, nutrition, agronomy). Further categorisation has been based on the degree of researcher or farmer management, e.g. research-managed, researcher-designed, farmer-designed and farmer-run, trials (Ashby 1985; Sumberg and Okali 1988).

The aims of trials in livestock systems research were discussed by Spedding (1984), while Bernsten (1982), De Boer (1984), Gryseels and Anderson (1985) and Petheram and Basuno (1986) listed problems likely to be faced in farm trials involving animals. In tropical countries, there is far less evidence of farm trials having been conducted with livestock than with crops: and coincidentally there has been much slower progress in improvement of livestock than of crop components of systems (e.g. Zandstra et al. 1981; De Boer 1984).

However, publications such as those of Nordblom et al. (1985) and Amir and Knipscheer (1987) suggest that the subject of livestock farm trials is beginning to receive more serious attention. Farmer participation in the design and management of trials has become a popular topic in the agricultural literature (e.g. Arnon 1981; Matlon et al. 1984; Ashby 1985; Kategile 1985; Farrington 1988; Essers et al. 1989).

The aims of farm trials in DAP-oriented research appear to be related largely to the stage of the FSR procedure. Trials reported early in FSR programs are usually conducted to help diagnose constraints or to provide information on existing innovations that appear to have potential, while later trials are designed to test and adapt new ideas for practicality. Later still in FSR, farm trials are used to test or compare (and demonstrate) specific technologies or packages proposed as improvements to the system.

The disciplines under which most farm trials on DAP have been conducted are those of *agricultural engineering* (implements, harnesses and tillage), *animal science* (feeding and nutrition) and *agronomy* (e.g. land preparation, forage supply). Trials of forages on farms are particularly common, because forage introductions can often be made within farmers' resources and abilities. Many farm trials are poorly documented in the literature, so the examples in this paper are drawn mainly from work in Indonesia, which is familiar to the authors. A list of broad types of farm trials, which have been used in the development of DAP-related technology, is provided in Table 1. Where examples are drawn from Africa or Asia, the location is shown in parentheses.

Under each of the categories of trial listed in Table 1, various levels of researcher/farmer participation

Table. 1. A broad classification of types and examples of farm trial on DAP (mainly from Indonesia).

Type and aims of farm trial	Examples (mainly from Indonesia)
1. *Studies of existing farmer innovations* To determine potential for improvement through *existing* local innovations, and reasons for their nonadoption by other farmers.	Metal plough shear used by some farmers, while others use wooden shear. Single animals used by some farmers while most use pairs.
2. *Exploratory tests* To establish feasibility of an idea, based on practicality and farmer opinion.	New harness design. New feeding practice.
3. *Adaptation trials* To adapt an idea from other areas to local material and conditions, with farmers' assistance.	New harness, padded with local material, e.g. kapok or sheep skin. New plough shear fitted to local base.
4. *Diagnostic trials* To verify ideas about suspected constraints to system productivity.	Sodium deficiency in forage. Sea salt supplement trial. Ploughing inefficiency. Test of animals' ability to pull heavier plough (load).
5. *DAP introduction trials* To introduce DAP use where no DAP implements currently used. (Involves training in animal training and plough making.)	Comparison of traditional land preparation (hand labour and animal trampling) and DAP implement use.
6. *Trials of new DAP operations* To test and demonstrate the practicality and value of DAP equipment new to a farming domain.	Animal-drawn carts, where transport is a constraint.
7. *'Best-bet' trials of technology* To assess response in productivity (or performance) to apparently obvious solutions to overcoming known constraints. To assess farmer opinion and likely adoption.	Introduction of new weeding implements for use in dryland maize or cassava. Planting of tree forages to reduce labour for feeding in dry season. Preservation of rice straw to reduce labour in DAP rearing.
8. *Levels trials* To determine the optimal level of input and yield improvement desired by farmers.	Ploughing frequency trial in land preparation using DAP. Weeding trial, in establishment of forages for feeding DAs.
9. *Trials involving communal farmer action* To test and demonstrate the practicality of communal cooperation of farmers. To obtain data on work rates, costs and farmer opinion.	Earth dam construction (e.g. ILCA and Zimbabwe), using DA and scoops. Contour construction (Zimbabwe). Water-lifting devices (Thailand). Tool carriers (ICRISAT, India).
10. *Long-term demonstration/trials* To test long-term feasibility of technology combinations, and to demonstrate to farmers and extension. To assess farmer opinion re adoption or modification.	Dry season ploughing, to reduce runoff and weeds (Botswana). New harness and implement combinations found on stations to be superior.
11. *Animal health remedies/trials* To test available and cheap remedies to known health problems and to assess effectiveness and farmer adoption.	Toxocara control in buffalo calves. Control of biting insects in animal pens.
12. *Minimum tillage trials* To test practices aimed at reducing the DAP requirement. To measure reduction in DAP use, input and yield differences, and farmer opinion.	Minimum tillage implements and practices (Zimbabwe and Swaziland).
13. *Trials to improve profitability of DAP enterprises, through faster growth rates* To test various cheap feed supplements as means of increasing growth rates in offspring of DAs.	Rice bran/urea and molasses/urea supplementation of local forage.
14. *Demonstration units for policymakers* To test and demonstrate feasibility of, and need for, interventions to improve the DAP system.	Approved bull scheme in villages. Communal forage planting scheme. Credit packages for DAP. Cattle scales at markets.
15. *Trials of new land forming/cropping systems* Development and evaluation of DAP equipment and accompanying technology for improved farming systems.	Raised-bed farming practices for drainage of cereal crops on Vertisol soils (ILCA, Ethiopia).

Note: Various levels of researcher versus farmer design and management of farm trials is reported, e.g. farm researcher-designed and managed to farmer-designed and managed trials.

are possible. Although the literature on DAP research indicates that researcher-designed and managed trials are usually intended, the involvement of farmers' animals and land in trials invariably means that farmers have some influence on the design and conduct of trials. The most encouraging results from farm trials reported, however, tend to be those in which active farmer participation has been sought from the start (e.g. Anderson and Astatke 1987, in pond construction with farmer groups in Ethiopia; and Liem et al. 1989, in introduction of DAP implements in West Timor).

Evaluation Criteria in Farm Trials

From the reports studied of farm trials on DAP topics, the following list of criteria that have been used in the evaluation of technology in farm trials is revealed:

- feasibility — does it work at all?
- practicality — does it work on farmer's animals/land?
- adaptability — can it be modified to work on farms?
- statistical difference — is response statistically better than with traditional methods (e.g. crop yield or tillage rate)?
- cost — is cost comparable to existing practice?
- cost effectiveness — do the benefits exceed the extra costs?
- other inputs — are other inputs greater than with traditional practice (e.g. labour)?
- resource availability — are the extra inputs available?
- farmer opinion — do the target farmers like the idea, and do they have ideas for modification?
- farmer adoption — are farmers adopting the new idea voluntarily? If not, why not?
- interventions needed — what conditions (interventions) are needed to promote adoption (e.g. credit, market, drugs)?
- retrospective farmer opinion — what do farmers think/advise, e.g. 5 years after trial?
- sustainability — does the idea survive in the system, e.g. 5 years after introduction?

Realistic Design and Examples of DAP-Related Technology

Reports of farm trials on crop components of farming systems suggest that it is sometimes possible to undertake quite complex trials, e.g. a 3 tillage practice × 3 variety factorial design with rice. However, Byerlee (1985) pointed out that many FSR programs have become mired in numerous 'n × n' factorial experiments, which have little bearing on improvement to the system. Though factorials are ideal experimental layouts for examining interactions when sufficient replication and adequate control exist, if the focus of an experiment is on main effects and the variability of observations is large, then simpler designs are essential.

Trials involving comparisons of draught animals (e.g. in terms of work output, growth or calving rate) on small farms have certain limitations. Because farmers have so few animals (e.g. 1-2 per farm), several farms must be used for each treatment, with a single treatment per farm. High variability between farms and animals means that the number of farms (and amount of research labour) required for more than two treatments becomes prohibitive, unless vast amounts of research labour are available (Petheram and Basuno 1985). Thus, two treatments (including a control) are usually the practical limit.

Complex aims or design in farm trials with livestock are not only impractical, but usually unnecessary. Farm trials conducted with DAs invariably have to be small (2–20 farmers), informal, and evaluation criteria relating to farmer opinion are often more important than statistical differences in yield between treatments.

In West Java, a modified plough was developed to improve the rate of ploughing by paired buffalo, which are known to be capable of much higher draught than was demanded by the traditional plough. In trials on farmers' fields and animals (n = 6), the new plough resulted in a 26% increase in ploughing rate, and the same 'quality' of ploughing (Sumanto 1989). The data on ploughing rate (hours/ha) were, however, less valuable than data on farmer opinion, which revealed that most farmers would not adopt the plough, mainly because they are paid by the day (not per unit area) for rental of their DAP team.

Data on farmer opinion of new ideas may, of course, be treated statistically, and if properly collected can be valuable in the choice and design of technology. One aspect not brought out in Table 1 is the requirement for *long-term* assessment of farmer opinion of technology tested in farm trials.

A farm trial in Madura of three different feed supplements (molasses, rice bran and urea) in 1983, showed no significant differences between treatments, and there was a general lack of interest amongst farmers in the supplements at the time. When these farmers were visited 2 years later, they *asked to purchase the feed supplements originally used in the trials (on credit), because the growth of their young animals in years following the trial had seemed comparatively poor (Petheram 1987).*

Long-term evaluation is an essential feature of *forage trials* on farms because species that do well in the first year may not persist, and vice versa. Standard measurements of growth rates and yield in plots in one season can be almost worthless in assessing the long-term survival and value of forage species in village conditions. Ease of establishment and management, long-term survival at prevailing fertility levels, farmer opinion, availability of forage at critical times, and savings in labour, are usually the most important criteria in assessing forage introductions on farms.

Farm trials designed to simultaneously test and demonstrate new technology (10. in **Table 1**) are mainly concerned with comparing new methods with traditional practices, in terms of yield (e.g. of crops) or performance (e.g. of animals or implements). Such trials-cum-demonstrations may involve several components of the system (e.g. Jutzi et al. 1986) which have to be established on farms over time, and which need more than one season for farmers to learn to manage. Evaluation can only be in the long term.

Introduction of DAP and of new DAP operations (5. and 6. in **Table 1**) also requires the long-term presence of a researcher to ensure proper evaluation. It seems possible that some farm trials of DAP technology may have been prematurely discontinued on the basis of (short-term) lack of interest amongst farmers, while the technology itself may have been basically sound. Adequate exposure time and proper communication of ideas to farmers are essential in farm testing.

Farm trials of straw preservation and forage introductions in West Java failed completely in the first year. The survival rate of forage species was almost zero, and farmers showed little interest in the rice straw stacks, which their animals would not eat. Early in the next year, these farmers were taken to Central Java, to see the use of rice straw and 'improved' forages on farms. Following these visits, many farmers in the group achieved high forage species survival and were willing to make stacks and feed straw to their animals. Improvements in technical aspects of the trials (e.g. type of planting material) also contributed to success in the second year (Thahar 1989; Petheram et al. 1989).

In the above case, the technology itself (designed to overcome a well-defined constraint) was reasonably sound: the first year's farm trials failed mainly because of poor communication and hence inadequate motivation amongst farmers.

While it is generally not feasible in FSR to undertake large farm trials with multiple aims, it is sometimes possible to combine resources with other organisations to run trials designed to achieve a number of objectives in technology development. One such example is to utilise the labour and resources of agricultural schools in villages in large-scale farm trials and demonstrations of technology (Petheram and Basuno 1986). Another example is the use of large ploughing contests, to bring together different farmers, animals, equipment and practices, for comparison and demonstration from different areas.

In West Java, 32 farmers from four different villages gathered with their various combinations of cattle and buffalo in singles and in pairs, to compete in the Subang Ploughing Contest (Petheram et al. 1988). This allowed the comparison of the ploughing rate and ploughing 'quality' of various team sizes and animal species and provided useful data on the efficiency of land preparation per unit liveweight. The event attracted Provincial dignitaries, as well as the national news media, and led to the additional benefit of raising the status of DAP use and hence of encouraging the participation of farmers and extension agents in research on DAP.

The testing of means of communication (or transfer) of a technology can be a vital adjunct to the main aim of farm trials. In seeking farmer cooperation it is necessary to use effective means of communication and the methods found to be most effective can become part of the (tested) technology to be passed on to extension agencies.

In West Timor, metal ploughs were introduced to rice-growing areas over 20 years ago, but have never taken on widely, despite an abundance of cattle and training courses for local blacksmiths in making ploughs. In 1988, farm trials were run to compare the use of wooden ploughs from Java with various local tillage practices. To achieve this, a farmer from West Java was brought to Timor to train farmers (a) to train their animals for work, and (b) to make wooden ploughs. Local farmers and administrators were so convinced by the farmers' methods (and the benefits offered), that the simple technology has been accepted, even before the results of the trials became available (Liem et al. 1989).

The development of modern data logging equipment for recording draught, speed and physiological variables of animals working in the field has made possible the conduct of certain types of trial on farms, where previously these were only feasible under research station conditions. This equipment may have high potential for testing alternative implements with farmers' animals and conditions where animal draught capacity and stress are major issues. However, the high cost (and other priorities in DAP) place these techniques out of the reach of most programs of farm research at present.

Documentation of Farm Trials on DAP Topics

A serious difficulty in reviewing this topic has been the poor documentation of information on farm trials in the field of DAP. For example, in the proceedings of the first ACIAR International Workshop on DAP (Copland 1985) no mention of farm trials appears. Most scientific journals do not publish papers based on data from the relatively uncontrolled conditions of farm trials. Further, there is a reluctance amongst specialists who are involved in farm trials to publish results of research which they consider to be too far from the frontiers of science to gain professional recognition in their field.

Even short accounts of farm trials can be very valuable, if these mention aims, methods, sample size, results, farmer opinions, a brief economic analysis and conclusions. Such accounts (e.g. Stephen 1984) are rare in the literature. Most farm trials reported on DAP topics are those conducted by internationally established research programs with an FSR perspective (e.g. ILCA and CIMMYT).

The most comprehensive information on philosophy and methods in the conduct of farm trials is in recent literature (e.g. the Journal of Experimental Agriculture) on farmer participatory research in FSR (Farrington 1988; Essers et al. 1989). While methods in farm trials vary widely with discipline and aim of trials, a body of knowledge is accumulating on working with farmers in technology development in general, and in the conduct of farm trials in particular which can be valuable to those working in this field (Baker et al. 1988).

Involvement of Specialists and Extension Agents

The level of knowledge achieved in all disciplines related to DAP appears to the authors to be sufficiently high to warrant more emphasis on farm trials in future research on DAP. Encouraging results obtained even by nonspecialists in working with farmers to adopt and test ideas for improving DAP systems (e.g. Sumanto 1989), suggest that if more specialists became involved in the design and conduct of farm trials, the potential for improvement of systems could be much enhanced.

To illustrate this point, in Java there are numerous different traditional plough types developed by farmers. Virtually none of these have ever been studied by engineers. Yet the choice of ploughs for over 10 000 families placed on 'transmigration' farms each year is based entirely on plough availability; no data are available on the performance of Indonesian ploughs or their long-term effect on soils.

Similar potential for improvement through the involvement of specialists in farm research may be found in forage and crop agronomy, animal nutrition and other disciplines associated with draught animal power. An economic analysis should be conducted before and after all farm trials. The involvement of extension agents in farm trials would seem to be essential. If extension staff are involved in farm trials and convinced of the value of new technology, the chances for its rapid diffusion should be much increased. Extension workers can provide access for reseachers to farmer groups, and farm trials can provide extension staff with valuable practical experience in handling animals, crops and technology.

Cost of Farm Trial Programs

Experience in Java shows that the costs of conducting trials using farmers' animals, land (and even labour) can be very low, compared to most conventional research programs on stations. However, the existing high capital investment in stations and equipment tends to influence the allocation of research funds towards further expenditure on stations. Also, many organisations find difficulty controlling the funds needed for travel and support of field staff for farm trials. Farm researchers must have budgets for unpredicted but essential expenses. Where animals are involved, there is sometimes the need to insure farmers against loss of stock through sickness during trials.

Conclusions

Farm trials, as one part of an FSR procedure, are dependent on sound description and diagnosis of system constraints. Achieving a balance between descriptive research and farm testing is a critical element in the management of FSR. Also critical is the balance between experimentation on research stations and trials on farms. While design of farm trials is often dependent on data and advice from research stations, on-farm studies should provide information on constraints and conditions on farms, vital to the planning and conduct of experimental programs on stations.

Three major recommendations can be made from this review of farm trials of DAP technology. First is the need for better documentation of results (including methods, results, failures and reasons) by those involved in farm trials. Second is the need for more specialists and extension agents to become involved in farm trials, so that a sound scientific and practical basis is assured in the design and conduct of trials, and research on stations can become more relevant. In this context, the term 'specialist' includes technical expertise (e.g. skilled farmers, carpenters, mechanics) as well as PhD level academics. Finally, a plea is made to Australian and other research organisations to recognise that farm trials are an essential part of agricultural research in small-scale farming systems, even if they do not attract the glamour of other types of research.

A key requirement in the design of farm trials is simplicity. Low land and stock ownership and high variation usually preclude complex design of trials. Data relating to practicality and farmer opinion of technology are often the most important. A nonstatistical approach should not imply a lack of rigour, and demands innovation and careful design and evaluation of trials. DAP technology, and hence farm trials, should be designed for well-defined farmer domains (Tripp 1986). Finally, the conduct of farm trials is very time-consuming and requires strong conviction and leadership by committed scientists, and strong institutional support.

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Optimum Strategies for Draught Animals in Subang District, Indonesia

Edi Basuno*

Abstract

A group of linear programming models is under development to investigate the role of draught animal power in Indonesian village agriculture. This preliminary study looks at the effect on income that results from the renting of draught animals on farms that currently use manual labour only to prepare irrigated land for food crops. Results indicate a 12% income benefit for those farmers who rent out their animals; further increases in the technical efficiency of the draught animal system have only a small effect on the income of such farmers.

Introduction

IN 1986, Indonesian and Australian institutes started collaborative research on the role of draught animals and draught animal power (DAP) in Indonesian farming systems. One objective was to provide a better definition of the economic functions of DAP, to improve understanding of the current contribution of DAP and an assessment of the changes that might occur if changes were made to DAP systems.

An initial decision was made to construct explanatory models of current practices. This was based on the general assumption that farmers are efficient in the utilisation of resources available to them: they cultivate their land to achieve some optimum result and the practices displayed are an expression of these optima. This modelling approach places DAP firmly within an appropriate context: it is to be treated as one input to a complex production process and, through manipulation of the model, the effect of changes in the DAP component can be judged relative to resultant shifts in other inputs and the effects on income and output.

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One problem associated with any whole-farm modelling approach is the need to devise models that are both representative of a particular situation and sufficiently plastic for use in similar systems. This problem is compounded by the diversity exhibited in Indonesian agriculture. The range of environments and the multiplicity of resultant systems are both well known and need no further comment. Such variation continues at the micro level, affecting the farmer's decision-making in ways that are not obvious to the outsider. For example, land tenure can include ownership, sharing and rental arrangement; animal tenure displays a similar range; families rent-out their own labour while renting-in other labour. This tangled web of possibilities poses a daunting challenge for a model builder: is it possible to replicate a system in which production goals can be reached by the deployment of many different strategies?

Some circumstances affecting DAP within Indonesian agriculture do aid the modeller. Firstly, most DAP usage is associated with wetland rice cultivation, either on irrigated or rainfed fields. There is little current use of DAP for dryland crops. Secondly, most farms do not rear cattle or buffalo but most will use some DAP in rice land preparation. Thus the renting-in of draught animals for preparation of flooded land (*sawah*) for rice cultivation is common throughout Indonesia. This paper addresses such a situation. The results are preliminary because the model is still in the process of construction and validation. Future papers will address similar problems of farm organisation for farmers who rear large ruminants for use on their own land or for renting-out.

Objectives

The analysis and paper have three major aims. The first two deal with methodology and the third with results:

(1) Can a general model be constructed that simulates farmers' activities in a defined current system?

(2) Is the model sufficiently robust for use, with appropriate modification, in related systems?

(3) Does the renting-in of DAP for land cultivation increase the 'profit' of farmers who do not rear large ruminants?

Methods

Analytical Technique

An early decision was the use of Linear Programming (LP) to develop and express the model. LP was chosen because it is a simple, powerful and precise economic planning technique. If the problem has been correctly specified, and if the data on which it is based are sound, LP will produce maximum-profit farm plans.

Data Sources

The choice of technique is an important influence on the type and quality of data required. Draught animal power is a subsystem of rice production which, in turn, is a distinct part of the individual farm system and wider regional systems. Draught animal power itself contains numerous associated components such as number, type and sexes of animals, working periods, feed and husbandry needs. It was apparent that highly detailed and divisible data would be required to meet this information need. A monitoring study of 80 farmers in the Subang district was run for 1 year covering, where possible, all aspects of their farm management plus off-farm labour usage (Basuno and Perkins 1988). These data have been used in the analysis, supplemented by other data collected by research workers in the same region.

Analytical Structure

The matrix of possibilities is as great in Subang, the study site, as other areas of Indonesia. Both irrigated and rainfed *sawah* areas are utilised for a variety of cropping patterns, including many combinations of rice, secondary crops (*palawija*) and fallow. Some 90% of the farm households do not rear large ruminants and land can be tilled by either manual labour, DAP or some combination of both. A small amount of tractor tillage was observed but has been excluded at present. The analysis has concentrated on modelling a composite farm derived from data for five farmers who used manual labour only (either family labour or hired labour) for preparing land for rice cultivation. This enabled the introduction of the first test: if DAP was introduced to these labour-only farms, would any income benefit result?

This first test was then applied to a number of labour-only farms, differentiated by their pattern of crop types and crop rotations. A second major analysis then proposed an additional hypothesis: if technological change resulted in a quantifiable increase in DAP efficiency, what effect would be noted on a farm renting DAP for land preparation?

Model Farm

The basic model farm has 0.25 ha of irrigated land and 0.15 ha of rainfed land. The average number of family labourers was 1.4 males and 1 female. Family labour can be used for both on-farm and off-farm activities as well as for work in the nonagricultural sector. Apart from operating their own farm, farmers had the option to rent or share-in land, as well as renting or sharing-out their own land. Money can be borrowed from various sources, such as a bank, the village cooperative, moneylenders, relatives or close neighbours. A schematic outline of the model used in this paper is given in Table 1. Selected detail of the rice cropping activity is contained in the Appendix. Full details of the model will be published at a later stage but are available from the author on request.

In the model each of the crop production activities required different amounts of resources, e.g. land, labour (human and/or animal) and cash. In return each activity provides a crop yield to the farmer. Sales of harvested crops contribute to the cash supply for the month of sale. Activities concerned with renting and sharing land may contribute to, or take from, the land and cash supplies rows which depend upon whether farmers rent/share-in or rent/share-out the land.

One of the challenges of modelling Indonesian rice farms is to account for the multiple uses of family labour. In fact, about one-half of the model

Table 1. Schematic outline of farm model.

Resource	Activity: Crop prod.	Crop sale	Land rent/ share	Use fam. lab.	Hired lab./ animal	Credit	Cash Transfer	Off farm/ nonagr.
Land	+	0	+/–	0	0	0	0	0
Family labour supply	0	0	0	+	0	0	0	+
Labour requirement	+	0	0	–	–	0	0	0
Crop yields	–	+	0	0	0	0	0	0
Cash supply	+	–	+/–	0	+	+/–	+/–	–

Table 2. Optimum plan for rice production on irrigated land and *palawija* on rainfed land.

Activity	Optimum Plan Manual	Animal	Unit
Paddy-Paddy	0.57	0.03	Ha
Cucumber-Cucumber-Bean	0.10	0.14	Ha
Mungbean-Cucumber-Cucumber	0.05	0.01	Ha
Rent-in irrigated land	0.50	–	Ha
Rent-out irrigated land	0.18	0.22	Ha
Share-in irrigated land	–	1.26	Ha
Sell paddy	5.40	7.46	Tonne
Sell cucumber	4.70	4.71	Tonne
Sell bean	3.04	4.07	100 Bundles
Sell mungbean	0.05	0.01	Tonne
Fam. male labour on-farm	49.00	84.14	Day
Fam. female labour on-farm	99.70	75.89	Day
Hire-in male labour	152.70	218.36	Day
Hire-in female labour	50.40	144.68	Day
Hire-out male labour off-farm	284.40	259.28	Day
Hire-out female labour off-farm	163.50	174.00	Day
Total gross margin	1855.56	2085.75	Rp.1000

Table 3. Optimum plan for rice and *palawija* on irrigated and *palawija* on rainfed land.

Activity	Optimum Plan Manual	Animal	Unit
Paddy-Bean	0.58	0.48	Ha
Cucumber-Cucumber-Bean	0.10	0.12	Ha
Mungbean-Cucumber-Cucumber	0.05	0.05	Ha
Rent-in irrigated land	0.33	0.23	Ha
Share-in irrigated land	–	0.31	Ha
Sell paddy	4.25	5.63	Tonne
Sell cucumber	4.71	4.70	Tonne
Sell bean	20.11	17.75	100 Bundles
Sell mungbean	0.05	0.03	Tonne
Fam. male labour on-farm	90.97	84.38	Day
Fam. female labour on-farm	133.03	136.31	Day
Hire-in male labour	172.53	181.99	Day
Hire-in female labour	135.69	138.47	Day
Hire-out male labour off-farm	242.42	249.01	Day
Hire-out female labour off-farm	138.64	132.15	Day
Total gross margin	1997.56	2154.43	Rp.1000

Table 4. Family labour (in days) for rice on irrigated land and *palawija* on rainfed land.

Activity	On-farm		Off-farm	
	Manual	Animal	Manual	Animal
Land preparation	23.40	36.12	54.61	45.88
Harvest				
— Male	-	-	65.80	65.80
— Female	8.91	20.04	15.09	22.94
Other tasks				
— Male	25.60	38.00	163.99	147.60
— Female	90.78	65.87	148.40	151.05

Table 5. Family labour (in days) for rice and *palawija* on irrigated land and *palawija* on rainfed land.

Activity	On-farm		Off-farm	
	Manual	Animal	Manual	Animal
Land preparation	29.46	20.94	48.53	57.12
Harvest				
— Male	-	-	65.80	65.80
— Female	9.34	12.55	24.00	24.00
Other tasks				
— Male	61.51	63.44	128.10	126.09
— Female	123.69	235.76	114.64	108.15

is devoted to this problem. Some uses, such as land preparation and harvesting, have wages which differ from the majority of other tasks (e.g. weeding and transplanting). Therefore, the activities which use family labour or allow the hiring-in or -out of labour must be differentiated by task. For the purposes of this model the separate tasks are land preparation, harvesting, nonagricultural work and 'all other agricultural tasks.' Cash is modelled on a simple cash-in, cash-out basis at the time transactions occur. Cash can be borrowed on a monthly basis or saved and transferred from one month to another. Household cash requirements were specified as the minimum (unavoidable) expenses such as food purchases, health expenses, clothing and various social contributions. These must be generated by the farm activities, nonfarm activities or borrowed. Both labour and cash are modelled on a monthly basis. The objective function is the maximisation of total gross margin, i.e. gross return minus variable (usually cash) costs.

Results

In order to look at the outcome of the model for two different types of land preparation (manual versus animal) two strategies were adopted. First, the model was limited to the production of rice on irrigated land with *palawija* crops on rainfed land. The second strategy allowed rice and *palawija* on irrigated land. In each case the model was run with manual land preparation only and then with a choice of manual and animal methods.

Solutions indicate that when DAP was introduced there was a gain in total gross margin of 12% for rice-only production and 8% when rice and *palawija* rotations were included. In both cases the organisation of the farm altered with the introduction of animal cultivation, as can be seen from Tables 2 and 3. The change from manual to animal technique increased the size of operated irrigated land. In the rice-only rotations, for instance, DAP usage enabled the operated land area to increase from 0.89 to 1.07 ha (17%), through sharing-in more land. A similar tendency occurs in the rice plus *palawija* rotations, but the increase in land area was less, i.e. from 0.91 to 1.02 ha (9%). The gross margin gain was also less than for the rice-only rotations.

In relation to the family labour, the solutions did not show a consistent indication that animal usage would decrease participation of family labour for on-farm activities. In the rice-only rotations, for example, animal usage would increase family labour for on-farm land preparation as a result of the larger amount of land operated (Table 4). For the rice plus *palawija* rotations it would decrease family labour participation on the farm and increase the off-farm participation in land preparation as shown in Table 5.

The next test looked at the effect of changes in efficiency of DAP usage. Animal days/hectare were reduced by 10%. No assumptions were made regarding how this change might occur, e.g. improved nutrition or reduced stress. Such an improvement resulted in a 4% improvement in total gross margin in the case of rice and *palawija* rotations.

Discussion

Because LP is an optimising technique it is difficult to judge whether this is a valid model of a Subang rice farm. Nevertheless the model makes predictions about farm organisation which are similar in form to actual practices, for instance, the inclusion in the model of various land arrangements which exist in the area, different labour allocation for different tasks, different wages for different type of work, etc.

The results show that introducing contracted animal cultivation, *where it is technically feasible to do so*, into farms which previously used manual cultivation can both pay the costs involved and increase the total gross margin.

Solutions suggest that improving efficiency of animal usage for land preparation does not give a substantial gain in total gross margin to farmers who rent-in the improved DAP system. The benefits of such improvements may lie with the rearer and operator of the animals: this question will be addressed in later papers.

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Appendix

Restraints

The average figures for irrigated land and rainfed land among manual farmers were 0.25 and 0.15 ha respectively.

Human labour was divided into family and hired labour. Family labour supply was limited while hired labour was assumed to be unlimited at the current wage rate. Labour usage was measured in person-days and specified as monthly constraints from January to December. In calculating family labour availability, it was assumed that people work 7 days a week, less a 20% allowance for various other purposes such as sickness (1 day/month), attending parties (2 days/month), mutual-work (2 days/month) and travel (2 days/month).

Family labour involved in various activities outside the agriculture sectors was also limited to a maximum of 60 days/year, based upon the average figure from farmers' records.

To start cropping farmers were allowed to borrow money from different sources. The amount which could be borrowed was limited to Rp. 100 000/year. Cash at the start of the cropping year in this model was zero but this can be varied.

Activities

On irrigated land two different methods of land preparation were considered, i.e. by manual methods and by animals. Land preparation for the first crop starts at the beginning of the rainy season (October/November). Rotations on irrigated land were paddy-paddy-fallow and paddy plus secondary crops such as cucumber, bean, mungbean and peanut, followed by fallow. For instance, there were combinations of paddy and cucumber; paddy, cucumber and bean, etc. Because paddy is regarded as a priority crop for most farmers, all secondary crops were grown after rice.

On rainfed land only secondary crops were considered. These activities represent a combination of two or more secondary crops (e.g. bean-cucumber; cucumber-cucumber-bean).

In the area studied, operated land is not always owned by the farmer. Some farmers cultivate their own land as well as land owned by someone else. To accommodate this situation renting-in irrigated land for a cash payment was permitted. Under this system, tenants provide all inputs as well as labour beside renting cost and all the yield goes to the tenant. Renting-out the farmer's own irrigated land was also permitted. In this case the farmer will receive the rent but does not control the use of the land.

Share farming arrangements were also modelled. Here, inputs usually are shared equally between the landowner and the tenant, but daily management is carried out by the share farmer and the yield will be shared equally. In line with the usual village practice, it was assumed that this arrangement follows only the paddy-paddy rotation. In sharing-out irrigated land the owner will provide half of the inputs and receive half of the yield. As in the sharing-in activity this was only for the paddy-paddy rotation.

Crop products were available for selling. The price of each commodity was based on the price during the period of study. Prices for paddy, cucumber, bean, mungbean and peanut were Rp 210/kg, Rp 70/kg, Rp 40/bundle, Rp 625/kg and Rp 280/kg respectively.

Labour usage for farming can be divided into three different activities (i.e. land preparation, other tasks (various maintenance duties) and harvest). This division applied for both family and hired labour. Apart from land preparation for paddy (mostly done by males), all farming activities are carried out by both males and females. The cost of hired labour for land preparation was Rp 1500/day, for other tasks it was Rp 1250/day for males and Rp 1000/day for females, while the average harvest share received was 22 kg paddy/day for both males and females.

For family labour, there was also the opportunity to work on the farms of others. Wages received for such activities were similar to the amount when labour was hired in.

If animals were hired for land preparation, the cost per unit — either single or pair — was Rp 3500/day. In addition, a meal was provided which cost approximately Rp 500. In normal practice a work-day of animals varies from 4 to 6 hours.

Another opportunity for family labour was to work outside the agricultural sector. It included activities such as being a carpenter, tailor, 'gamelan' player, various trader. These types of activities are mostly done by males, and restricted only for 60 days/year with the average income of Rp 3000/day.

To finance farming activities, some farmers borrow money. In the model, credit was assumed obtainable every month with an interest rate of 5%/month (the rate charged by the Village Cooperative Unit).

As an example, the resource requirements for rice production are presented as follows:

Aggregate resource requirements (per hectare) for paddy-paddy-fallow:

Resource requirement	Level
Irrigated land (ha)	1.0
Male labour (days)	97.5
Female labour (days)	99.3
Land preparation labour (days)	86.0
Harvesting labour (days)	62.0
Cash (Rp. 1000)	116.0
Yield (tonne)	6.8

Note: all resource requirements are further disaggregated into monthly figures.

Section 4

Draught Animal Production: Nutrition and Physiology

Nutrition of Draught Animals

E. Teleni* and J.P. Hogan**

Abstract

In this review, some of the areas of knowledge and ignorance in the nutrition of draught animals are highlighted. The need to define more clearly the types of work undertaken by draught animals and associated energy expenditures is discussed. The utilisation of nutrients by draught animals is also discussed. While the importance of free fatty acids and glucose in working muscles is well accepted, there appears to be little quantitative data on their use, particularly in working cattle and buffaloes. Futhermore, the partitioning of these energy-yielding nutrients between the lactating mammary gland or the pregnant uterus and muscles requires investigation. Results of studies on the effect of work on feed intake by cattle and buffaloes are inconsistent, and further research is required to explain the reasons for the inconsistencies. Probable differences between cattle and buffaloes in their capacity to utilise feeds, particularly low quality feeds, are discussed. The importance of some of the basic knowledge on the role of body reserve nutrients in the rationalisation of feeding systems for draught cattle and buffaloes is highlighted.

Introduction

It is recognised that in areas of the world where draught animals have a special niche, human population pressure per unit area of useful land is generally intense, climatic conditions are normally tropical and the animals are normally subjected to marked fluctuations in nutrient supply in any given year. Given these sorts of pressures, it is incumbent on all workers in the area of draught animal use that one of the goals aspired to is the optimisation of the use of draught animals. Important to the attainment of such a goal are the considerations that:

- draught animals are part of animal production systems in which work output is an indispensable animal product, and
- that such animal production systems should be integrated into agricultural systems in a manner which is least competitive with human needs, particularly for food and space.

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Within this context, it is clear that the greatest economy of feed resources in draught animal power systems must involve the use of the female animal not only for reproduction but also for work. In fact, as Devendra (1989) has indicated, there is growing interest in the triple-purpose animal producing calf, work and milk.

Many elegant views and discussions on aspects of the nutrition of draught animals have been presented in the past (e.g. Goe and McDowell 1980; Smith 1981; Goe 1983; Lawrence 1985, 1987; Leng 1985; Preston and Leng 1987; Lawrence and Smith 1988) and more recently (Ffloulkes and Bamualim; Upadhyay; Lawrence and Pearson; These Proceedings).

This review discusses facets of the energy cost of work, the utilisation of nutrients by working muscles and other tissues, nutrient supply and lessons that can be drawn from information on weight gain or loss. Because of the obvious dominance in usage of cattle and buffaloes as draught animals (Ramaswamy 1985) discussion is directed towards these species.

Nutrient Requirements

Work

Work is achieved through muscle contractions which are driven by adenosine triphosphate (ATP), the main energy currency of the body. Muscle function during work can be considered as a collaborative achievement of the respiratory and cardiovascular functions, and the various systems of ATP generation (Fig. 1). The overriding requirement by the working animal is for energy-yielding nutrients. Consideration of requirements for protein-yielding nutrients is likely to be relevant only in terms of their possible contribution to ATP production, either through their direct oxidation and as glucose precursors, or through their stimulatory role in digestive function, which results in increased availability of nutrients to animals on poor quality roughages.

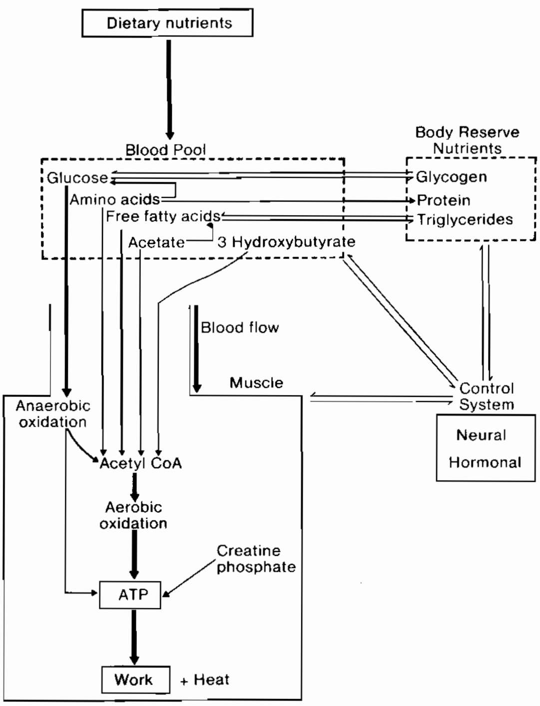

Fig. 1. The utilisation of energy-yielding substrates for generation of ATP for work.

Types of Work and Workloads

Although the various types of work that an animal can be subjected to are many, the major draught functions of cattle and buffaloes, in general, are in agricultural land preparations and cartage. Workloads imposed on the animals performing these functions can be quite varied, reflecting variations in tractive effort (draught force), duration of work and the speed at which the animals travel. Goe (1983) has summarised estimated draught capacity of several species. With cattle and buffaloes working at normal speeds ranging from 2.5 to 4.0 km/hour, the tractive effort developed may be equivalent to 10–14% of liveweight of the animal. From our own experience with cattle and buffaloes in Townsville, animals travelling at a speed of 2.5 km/hour and subjected to a draught load equivalent to 11% of their respective liveweights are quite distressed if worked continuously for 3 hours or more. This is similar to the finding by FAO (1982) which suggested that draught in excess of 8–10% of the liveweight of the animal travelling at a speed of 3 km/hour generates excessive stress on the animal. It was recommended that these might be considered as safe upper limits for animals working in ambient temperatures of 27–34°C. Further, it was also recommended that such animals should be rested for more than half an hour after a work period of 3–4 hours. This aspect is discussed in more detail by Upadhyay (These Proceedings).

Measurements of tractive efforts developed by buffaloes ploughing rice fields in Indonesia at an average speed of 2.5 km/hour showed a range from 60 kg (Sumanto, pers. comm.) to 80 kg (A. Bamualim and D. Ffoulkes, pers. comm.). It would appear that these animals were working at or near optimum workload. Hours of work/day may vary from 2 to 8 hours but it would appear that the normal range is from 3 to 6 hours/day. On Java, animals may be worked from 30 to 200 days/year (Petheram et al. 1985).

For convenience, a number of reports have classified workloads as *light*, *medium* and *heavy*. The bases for these classifications are not consistent (Table 1) and basing estimates of energy requirements of animals on them can be quite misleading. For example, estimated energy use by animals doing so-called *light* and *heavy* work (Lawrence 1985 — Table 1) were similar at 36.21 MJ and 36.55 MJ respectively. The need for a consistent standard of classification of workload is certainly highlighted and consideration of both intensity (tractive effort) and rate of work (power produced) as suggested by Goe (1983) should form a sound basis for classification.

Table 1. Classifications of work and workloads.

Work classification			
Light	Medium	Heavy	Reference
Sowing, light transport work	Harrowing, cultivating	Ploughing, chisel ploughing, training	Reh (1982)
Walking for 6 hours	–	Ploughing for 6 hours	Leng (1985)
Pulling 500-kg cart for 5.5 hours	–	Ploughing medium soils for 5.5 hours	Lawrence (1985)
Ploughing for 2 hours	Ploughing for 4 hours	Ploughing for 8 hours	Bamualim and Kartiarso (1985)

Energy Expenditure

Because of inherent difficulties of measuring energy expenditure of working animals under field conditions, there have been few available data on energy costs of the array of workloads to which draught cattle and buffaloes are normally subjected. It was not until the 1980s that various estimates, either derived from data on other species or directly from measurements in the field, began to appear in the literature. It would appear from these estimates that energy used by working cattle and buffaloes would range from 1.25 × maintenance (Pearson 1988) to 2.7 × maintenance energy requirement (Goe and McDowell 1980). The latter value is higher than the estimated requirement for maintenance + the production of 10 kg of milk/day (Fig. 2). Estimates of energy expenditure in working cattle,

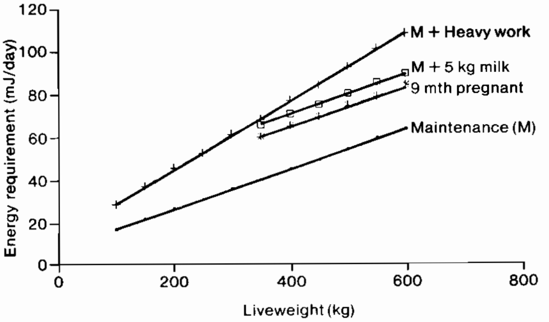

Fig. 2. Estimated metabolisable energy requirements for work (Lawrence 1985), milk production, pregnancy and maintenance (MAFF 1984).

derived from field measurements by Lawrence (1985) in Costa Rica, Barton (1987) in Bangladesh and Pearson (1988) in Nepal suggest that the high value of 2.7 × maintenance might be an overestimate and that an average upper value of 1.7 × maintenance as reported by Lawrence (1985) might be more realistic. In addition to the need to standardise bases for work and workload classifications, as mentioned previously, there is an obvious need for more data on energy expenditures of animals subjected to various types of work and workloads.

Trained vs Untrained Animals

Figure 2 illustrates the relationship between estimates of the total energy requirement for work and requirements for maintenance, pregnancy and lactation. It is of interest that with advancing liveweights of animals, the total energy requirement for work diverges from increases in maintenance energy requirement. This of course assumes that maintenance energy requirement is not affected by work, and that the energy expenditures of animals under a given workload are a constant proportion of their maintenance energy requirement. There is some evidence (Lawrence 1987) to suggest that at least with animals fed at a level below maintenance energy requirement, work can raise their resting metabolic rate by some 12%. Results of recent work in our laboratory suggest that resting metabolic rate is increased in trained female buffaloes compared to the untrained buffaloes (Table 2). Carbon dioxide entry rate, which reflects metabolic rate, was increased in the resting trained buffaloes by approximately 26%. A point of interest was the negligible difference, between trained and untrained animals, in mean CO_2 entry rate during the work period. This suggests that the trained animal used metabolisable energy (ME) more efficiently (approximately 6% more efficiently) than its untrained counterpart.

Further studies comparing the physically trained and untrained buffalo (Martin and Teleni 1989) showed that the untrained animal relied increasingly on anaerobic metabolism for its energy supply when required to pull a draught load equivalent to 11% of its liveweight at a walking speed of 2.5 km/hour.

Table 2. Mean CO_2 entry rates in six physically trained and six untrained female swamp buffaloes.[a]

	CO_2 entry rate (mg/min)			
Physical condition	Rest	Work (3 hours)	Recovery (3 hours)	Work/Rest
Untrained	4163	12010	6801	2.9
Trained	5227	12564	9558	2.4
Difference (%)	25.6	4.6	40.5	

[a] E. Teleni and R. Pieterson, unpublished data.

Table 3. Plasma entry rates and utilisation of energy-yielding nutrients in ruminants fed or fasted for 24 hours.[a]

	Entry rate $mg/min/kg^{0.75}$		% contribution to CO_2 production		% contribution to energy expenditure	
Nutrient	Fed	Fasted	Fed	Fasted	Fed	Fasted
Acetate	10.8	5.8	32	22	18	12
Glucose	5.0	3.8	9	11	7	8
Propionate	6.4	2.5	23	7	24	6
3-Hydroxybutyrate	1.4	1.5	10	5	11	4
		Total	74	55	60	30
Contribution of FFA[b]			26	45	40	70

[a] Adapted from Annison and Armstrong (1970).

[b] Estimated by difference.

The accumulation of lactic acid in muscle cells at this level of work, or higher, is likely to limit the work performance of untrained animals. Pulling draught loads equivalent to 5–8% of liveweight at the same speed of walking did not appear to increase the rate of glycolysis.

One of the implications of the observations discussed above is that it might not be cost effective to underutilise trained animals for work because of their higher maintenance cost and apparently higher efficiency of utilisation of ME for work. On the other hand, untrained animals might be more profitably employed for casual work with an upper draught limit of about 8% of liveweight, at 2.5 km/hour.

Liveweight

In Fig. 2, the diverging line for total energy requirement for maintenance + work from the line for energy requirement for maintenance suggests that the lighter animal would be more efficient than the heavier animal doing the same work. If it is assumed that the upper limit of tractive effort that can be sustained in a work period of 5–6 hours is equivalent to 11% of body weight of the animal, then the most efficient animals that can be subjected to a draught force of 30–40 kg would be in the liveweight range of 273–364 kg.

Utilisation of Nutrients

Draught cattle and buffaloes are normally fed high roughage diets. In many relevant regions of the tropics, these are largely made up of crop residues. It is well established that the carbohydrates in the diets of ruminants are largely converted to the volatile fatty acids (VFA), acetic, propionic and butyric acids. These acids make up approximately 70% of ME intake of the animal and on such high roughage diets as above, the normal molar proportions of acetic:propionic:butyric acid in the rumen would be approximately 75:15:10. On absorption from the digestive tract, most if not all the propionic and butyric acids are converted to glucose and 3-hydroxybutyrate respectively. As a consequence, acetic acid may account for approximately 90 molar % of total circulating VFA in the blood and contributes significantly to oxidative metabolism in the ruminant animal (Table 3). Table 3 shows that the type of substrate used as fuel will depend on the feeding management of the animal. Substrates (e.g. acetate and propionate) that depend largely on feeding levels for their concentrations in blood have a reduced contribution to oxidative metabolism during times of nutritional stress. The level of contribution by glucose in the early stages of fasting, at least, would be quite

Table 4. The calorimetric efficiencies of utilisation for maintenance and production of volatile fatty acids and glucose.

	Calorimetric efficiency for		
	Maintenance[a]	Fat synthesis[a]	Milk synthesis[b]
Acetic acid	59	33	
Propionic acid	87	56	
Butyric acid	76	62	
Glucose	100		
Acetic: butyric			
90 : 10	65		
Acetic : propionic : butyric			
75 : 15 : 10	86	32	54[c]
25 : 45 : 30	88	58	67[d]

[a] Blaxter (1962). [b] Annison and Armstrong (1970).

[c] Diet containing 100% lucerne resulting in molar proportions of VFA of 71:16:8 (acetic:propionic:butyric).

[d] Diet containing 40% lucerne and 60% concentrate, resulting in molar proportion of VFA of 60:26:10 (acetic:propionic:butyric).

stable due to the maintenance of the rate of gluconeogenesis by the liver. The biggest variables are the free fatty acids (FFA) which could increase their contribution to energy expenditure from approximately 40% in the fed animal to approximately 70% in the fasted animal. Indeed, an animal deprived of food can be expected to meet at least 80% of energy demand from fat and the rest from protein (Blaxter 1962).

The higher efficiency with which ME is used for maintenance relative to the efficiency with which it is used for fat or milk production is a well recognised phenomenon (Table 4). Although acetic acid on its own has been shown to be utilised at a relatively low efficiency for maintenance (Table 4), the presence of a little propionic acid in the VFA mixture (similar to that produced in a high fibre diet) resulted in a dramatic increase in efficiency to a level which did not fluctuate significantly with wide fluctuations in acetic acid content. At the production level, however, the efficiencies of utilisation of each of the VFAs are reflected in the variation in efficiency of utilisation of the different VFA mixtures. It is for these reasons that more attention should be given to the quality of the diet of a producing animal than to the quality of the diet of an animal expected to be at maintenance level. These reasons might also clarify the importance of knowledge of the substrates preferred by producing tissues such as the contracting muscle, pregnant uterus and lactating mammary gland — particularly in a situation where these tissues are competing for limited substrates.

Muscle

When work is imposed on an animal, thus effecting a compulsory diversion of relevant energy-yielding substrates to contracting muscles, metabolism is altered in a manner which is somewhat similar to that in the ewe during late pregnancy or in the cow during early lactation. During these periods FFAs are mobilised from fat depots even when the animals are reasonably well fed. This is consistent with the data shown in Table 5 and in Fig. 3. It appears likely that the impact of work on an animal is not only as a basic tax on its nutrient pool, but also as an important influence on the more subtle area of metabolic controls (Fig. 1).

There is compelling evidence (Table 5) that glucose and FFA are the principal metabolic fuels for contracting muscles in the working ruminant (e.g. Jarrett et al. 1976; Bird et al. 1981; Pethick 1984). These workers measured the uptake of these substrates by the hind-limb muscle of the exercising sheep and found substantial increases in uptake of the substrates by muscles during exercise. While it was generally concluded from these studies that the fate of the two substrates taken up by muscle was oxidation, the conclusion cannot be totally certain in the absence of direct evidence on the conversion of the substrates to CO_2. Pethick (1984) noted a rapid and sustained increase in the uptake of glucose by the exercising muscle while the uptake of FFA tended to increase throughout the exercise period. The simultaneous large uptake of glucose and FFA by muscles was somewhat surprising since controls

Table 5. The potential contribution of glucose and FFA to oxidation in the hind-limb muscle of sheep under different physiological states.

State	% of O_2 uptake by muscle	
	Glucose	FFA
Resting[a]		
Fed at maintenance level	37	12
1.5 × maintenance	31	11
Exercise		
Fed at maintenance level	17	81
1.5 × maintenance	11	57
Exercise		
At 15 min from start	21	15
At 120 min from start	29	40
Early pregnancy[c]	30	39
Late pregnancy[c]	38	64
Early lactation[c]	34	21

[a] Bird et al. 1981. [b] Pethick 1984. [c] Teleni 1984.

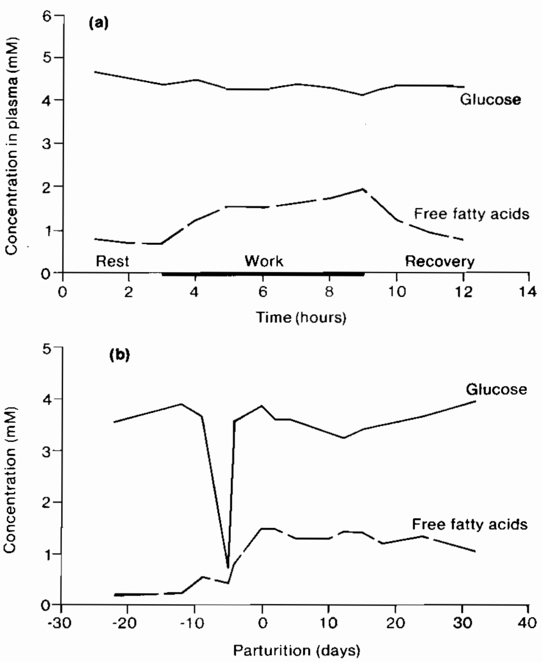

Fig. 3. Changes in mean plasma concentrations of free fatty acids and glucose (a) in working cattle and buffaloes (Kartiarso, D.G. Martin and E. Teleni, unpublished data) and (b) in cows in early lactation (D. Giesecke, pers. comm.).

of their oxidation in muscles are considered to be mutually inhibitory (Paul 1971). All the studies mentioned above were on wethers and it would be useful to know whether such large uptake of glucose as reported for the exercising hind-limb muscles would occur if the animals were females in late pregnancy or early lactation. Utilisation of glucose by skeletal muscle has been shown to be insensitive to changes in physiological state (pregnancy and lactation) in sheep, suggesting that there is an obligatory requirement by the tissue for glucose (Teleni 1984).

The uptake of acetate by muscle is very much diet-dependent. Low feed intake (e.g. at maintenance or submaintenance level) by the animal would result in a low uptake of acetate by muscle. Conversely, if the intake of feed was high, the uptake of acetate by muscle would be expected to increase. Exercise does not appear to change this pattern.

Most of the oxidation of amino acids occurs in the liver. The branched-chain amino acids are oxidised predominantly in muscles. The latter case is fairly well established, at least for the simple-stomached animals. The ruminant muscle has been shown to have a limited capacity to oxidise these acids — even in fasted sheep (Teleni et al. 1983; Teleni et al. 1986). It is more likely that the ruminant muscle facilitates the conversion of amino acids to glucose in the liver through its role as a supplier of amino acids, and its role in the transamination of some of the glucogenic amino acids (Teleni et al. 1986). There are no available data on the extent to which amino acids might be oxidised in muscles of working ruminant animals and it would be of interest to see whether working ruminant muscles do draw on amino acids, as energy sources, at certain nutritional levels.

In nutritional terms a distinction must be made between obligatory amino acids requirements for

Table 6. The urea kinetics in working and nonworking female swamp buffaloes fed rice straw ad libitum + 500 g cottonseed meal/head/day[a]

	Buffaloes	
	Working	Nonworking
No. of animals	6	6
Mean liveweight (kg)	320	320
Digestible organic matter intake (g)	2893	2943
Nitrogen intake (g)	74.01	76.91
Plasma urea (mg/100 ml)	30.5	27.4
Urea entry rate (g/day)	97.6	78.9
Urinary urea output (g/day)	32.4	25.2

[a] E. Teleni and R. Pieterson, unpublished data.

work and a capacity to oxidise surplus amino acids during work. It has been suggested (Lindsay and Hogan 1987) that a lactating 400-kg cow needs to supply from its intestines 171 g of amino acids to cover obligatory tissue losses plus a further 225 g to meet the needs for protein in 5 kg of milk. No corresponding data are available to indicate whether obligatory nitrogen losses increase during work. It would be surprising if this was not so. Equally, however, it is unlikely that the demands for additional amino acids for work would approach those required for milk. In view of the further calculation (Lindsay and Hogan 1987) that a forage diet, even of digestibility as low as 0.40 but with adequate rumen degradable nitrogen (N) can meet the amino acid requirements for lactation, it seems probable that the draught animal will frequently have a surplus of amino acids over its needs for protein metabolism. This may explain in part the role played by amino acids in the energetics of the working ruminant (Table 6).

The high urea entry rate in working buffaloes suggests that amino acids were catabolised in these animals for use as direct energy sources or as glucose substrates. The buffaloes were consuming approximately 1.23 × maintenance energy (in the form of rice straw ad libitum + 500 g cottonseed meal/head/day) and work involved pulling a draught load equivalent to 11% of liveweight at 2.5 km/hour for 3 hours/day. The glucose entry rate was not measured but based on previous experiments using the same animals it would be expected to be approximately 422 g/day. If it is assumed that the potential glucose synthesised is 1.57 g glucose/g urea excreted, then the amounts of glucose potentially synthesised from amino acids would have been 51 g/day in working and 40 g/day in nonworking buffaloes. These would have been equivalent to 12 and 9% of glucose entry rate respectively. It might be expected that at a level of ME intake of less than 1.23 × maintenance, even more amino acids would be used as energy-yielding nutrients.

To a large extent, two basic conditions determine whether amino acids (protein-yielding nutrients) are used as energy-yielding substrates. These are the relative availability of amino acids to that of the energy-yielding nutrients and the proportions of each amino acid (particularly the essential amino acids) in the available amino acid pool. If the energy-yielding nutrients:amino acids ratio were reduced or if amino acids were not in proportions which are compatible with protein synthesis, amino acids are likely to be used as energy-yielding nutrients. It should also be noted that the diversion of amino acids away from their primary function (i.e. as building blocks for proteins) might also be due to requirements by animals for so-called glycogenic substrates which may substitute for some of the roles that glucose normally plays under situations of glucose sufficiency.

Reproductive Tissues

Pregnant uterus Glucose is the major source of energy for the foetus. It is not until the last month of pregnancy that the pregnant uterus draws heavily on available body glucose. Setchell et al. (1972) estimated that the extraction of glucose by the pregnant uterus from the body pool could increase up to a rate equivalent to 70% of the entry rate of the substrate. Approximately 45% of the amount extracted is oxidised and the balance presumably is stored as glycogen. This is a vital process for the survival of the foetus at birth and it might be

Table 7. Entry rates of glucose and acetate and their utilisation in the whole body and lactating mammary gland of fasted goats and fed cows.[a]

Animal substrate	Whole body		Mammary gland	
	Entry rate (mg/min)	Contribution to CO_2 production (%)	Uptake (mg/min)	Contribution to O_2 output (%)
Fasted goat				
Glucose	93	3	40	10
Acetate	96	10	3	13
Fed cow				
Glucose	1037	8	555	37
Acetate	1979	34	145	7

[a] Annison and Armstrong (1970).

expected that the pregnant uterus near term would compete very strongly against other tissues for dispensable glucose.

Ovarian function An important aspect of reproduction that should be considered is the effect of work on ovarian function in female cattle and buffaloes. Results of recent work with cattle from our laboratories suggest that animals of reasonable body condition may stop cycling if they lose approximately 17% of their liveweight (Teleni et al. 1988 unpublished data). In animals weighing 338 kg this loss amounted to 56 kg. It appeared in this study that much of this loss was fat, resulting in a change of body protein:fat ratio from 0.96 to 0.24. It is unlikely that the cessation of cyclic activity was a result of direct competition for nutrients between the ovary and other tissues. It is probable that the depletion of body reserve nutrients to certain critical levels had signalled metabolic controls to switch off nonvital processes such as ovarian function. In the context of the draught female cattle and buffaloes in which markedly fluctuating body reserve nutrients might be the norm, it would be important to define further these lower critical levels of body reserve nutrients at which ovarian function is adversely affected. A clear definition of body weight/condition at the start of the work season and rate of weight loss which are compatible with normal ovarian activity is desirable. The effect of interaction between work and body reserve nutrients on cyclic activities of cattle and buffaloes is currently being investigated in collaborative studies between our laboratory and that of Balai Penelitian Ternak (BPT), Ciawi, Indonesia.

In a previous study at BPT (Bamualim et al. 1987) it was indicated that work per se might affect ovarian activity directly. Ovarian activity in the working buffaloes studied was reduced although the animals were slowly gaining weight. Clarification of this observation warrants further study.

Lactating Mammary Gland

The importance of glucose in lactation is illustrated by the data in Table 7. Glucose availability to the mammary gland can limit milk production. While glucose extracted by the mammary gland could account for 43% of glucose entry rate in the fasted goat and 54% in the fed cow (Table 7), other estimates suggest that lactose production in the udder could use as much as 60–85% of total glucose entry rate (Annison and Linzell 1964). At least 85% of the lactose carbon comes from glucose.

Acetate is used both for milk fat synthesis and as an energy source by the mammary gland. Both glucose and acetate may account for 71% of oxidative metabolism in the udder and the balance accounted for probably by 3-hydroxybutyrate since FFAs do not make a significant contribution as an energy substrate or as lipid precursors in the mammary gland.

Reports in the literature show a variable effect of work on milk production. Goe (1983) reported that on work days, cows may lose 10–20% of their milk yield. Assessment from Bangladesh (Jabbar 1983) also suggests a fall in milk production when cows are used for draught. On the other hand, studies using lactating buffaloes in Pakistan (Rizwan-ul-Muqtadir et al. 1975) showed no reduction in daily milk yield during work. The differences in responses reported were most probably a reflection of differences in availability of nutrients. If there were sufficient nutrients, no reduction in milk yield should be expected. Milk production of dairy cattle which were fed adequately did not drop when animals worked (Lawrence 1985). Matthewman (pers. comm.) recorded a reduction, from 5.89 to 5.26 kg/day, in daily milk yield of exercised Hereford × Friesian cows when fed to meet requirements for maintenance and milk production only.

On balance it might be suggested that the effect of work on milk production is directly through competition for nutrients by muscle and the mammary gland. Any situation that engenders intensification of such a competition is likely to result in a reduction in milk production since muscle contraction is a basic tax on the nutrient economy of the animal.

Partitioning of Nutrients

From preceding discussions it is clear that the productive tissues, viz. the gravid uterus, lactating mammary gland and the contracting muscle, have a specific requirement for glucose. The specificity of this requirement is such that a lack of glucose would result in cessation of milk production in the lactating animal or a nonviable foetus in the pregnant animal.

While it is clear that muscle has a minimal primary requirement for glucose, probably for the maintenance of glycolytic activity and the integrity of the TCA cycle (Teleni 1984), it is uncertain whether the increased and sustained uptake of glucose by muscle of exercising wethers (Pethick 1984) indicate a specific requirement for glucose by the tissue, over and above that required for glycolysis. It is conceivable that at the beginning of work there might be a surge in glucose carbon flux through the glycolytic pathway. At the normal speed at which draught cattle and buffaloes might walk (e.g. 2.5 km/hour) and the workloads to which they are normally subjected (e.g. developing a tractive effort equivalent to 8–11% of liveweight) it is likely that the dominant ATP-generating pathway would be aerobic oxidation (Fig. 1). During work, the release of the catecholamines and the reduction of insulin in circulating blood provide the hormonal milieu which is conducive to the hydrolysis of triglycerides to FFA from fat depots and their utilisation in muscles. These orchestrated events would most probably ensure the dominant role of FFA in energy supply to contracting muscles, although not to the exclusion of some minimal glycolytic activity. Such a course would be consistent with the need to conserve glucose in the ruminant animal.

When cattle and buffaloes are worked, there is an increase in glucose entry rate of approximately 84% (E. Teleni and D.G. Martin, unpublished data) and an increase in FFA entry rate of approximately 150% (Kartiarso and E. Teleni, unpublished data). The FFA entry rate is more than enough to meet the ATP requirements of the working muscles, and the prevailing hormonal milieu certainly is favourable for the oxidative dissimilation of the acids in muscles. The question that arises is that in the absence of a major sink, other than muscles, for glucose, what is the fate of the increased glucose entering the blood pool of the working animal? It is possible that the high uptake of glucose, observed in other studies with sheep, was involved in glycogenesis. If the animals were in late pregnancy or in lactation, it is possible that increased glucose entry might be accounted for by the pregnant uterus or lactating mammary gland rather than by muscles. If this is the case then the availability of glucose, in the above context, for the pregnant uterus or the lactating mammary gland of working cattle and buffaloes might not be a problem that it is purported to be. There are no data available on the role of working muscles in the utilisation of glucose in the late pregnant or lactating ruminant animal and further studies are certainly required in this important area.

What is clear from preceding discussions is that the FFAs have a dominant role in the energetics of the working muscle. The gravid uterus and the lactating mammary gland do not appear to have a specific need for these substrates, although the FFA play an important role in supporting physiological states by meeting to a large extent the whole body energy demands of the pregnant or lactating animal.

Recovery After Work

Little study has been made of the partitioning of nutrients in recovery of weight loss during extended rest periods in working animals. With lactating animals, work by the Townsville group has indicated that postpartum supplementation with energy and protein failed to add weight to the Zebu cross cow during the first 3 months of lactation, the additional nutrients being directed towards increased milk production (C.S. McSweeney, pers. comm.). This diversion of nutrients was sufficiently great to retard return to oestrus, but the ovarian cycle was resumed promptly when lactation stopped following the removal of the calf (C.S. McSweeney, P. Jolly and K.W. Entwistle, pers. comm.).

Despite the apparent similarity in nutrient demand for lactation and work, as discussed above, it seems unlikely that the hormonal control of nutrient partitioning will be the same in the two physiological states. However, there has been little study of the metabolic events in the tissues following the cessation of work, especially when the work period has been long and tissue reserves severely depleted.

Nutrient Supply

The capacity of the animal to meet its nutritional requirements, whether expressed as energy and protein or as specific nutrients such as glucose and individual amino acids, depends on feed intake, the release of molecules in the digestive tract and the metabolic decisions taken on the fate of those molecules in the tissues.

Feed Intake

Feed intake is controlled by signals to the brain indicating hunger or satiety (Weston 1985). In broad terms, the animal feels the need to resume eating when the effects of previous meals have been reduced. Such effects include the accumulation not only of metabolites and of heat in the tissues but also of digesta in the rumen. With increased demand for nutrients as a result of work as with lactation, the tissues signal the need for increased feed intake. The extent to which the animal responds will be determined by contrary signals arising from the rumen or from the tissues. This probably explains the contradictions in the literature in which work may be associated with no change in feed intake (Bamualim and Ffoulkes 1988), a reduction (Table 6), or even an appreciable increase if the work periods are short (Wachirapakorn and Wanapat 1989) or the animals are kept cool (Bakrie et al. 1989).

The capacity of the animal to reduce the effects of previous meals depends on efficient tissue metabolism and on effective reduction of digesta load in the rumen. Improved tissue metabolism was probably responsible for the increased intake of mature forage in Zebu cross cows supplemented with protein meals above those obtained with urea supplements (Lindsay et al. 1982). Similarly, the rate of removal of lactic acid from the tissues of working animals could perhaps be limited through inadequacy of thiamin synthesis by rumen microbes as appears to happen with sustained feeding of molasses. Deficiencies of minerals other than nitrogen and sulfur probably also depress feed intake more through action on tissue metabolism than on the rumen microbes (Little 1986). A prime example is cobalt deficiency which affects the animal through a deficiency of Vitamin B_{12} to the tissues.

However, it is probable that the major limit to feed intake with most draught animals is the rate of removal of feed residues from the rumen. The forages consumed by ruminants comprise readily fermentable parts such as the mesophyll and epidermal tissues and more resistant generally highly lignified tissues such as the vascular bundles. The removal of feed from the rumen therefore commences with the fermentation of the weaker cells, with associated removal of the products of fermentation by eructation, transport across the rumen wall or passage in solution with the digesta leaving the rumen. It is unlikely that the rate at which the three latter processes occur limits intake (Weston 1985). The major limit is imposed by the rate of removal of unfermented residues, which must be reduced to a size (<1 cm) and specific gravity (1.2–1.6) appropriate for propulsion through the reticulo-omasal orifice. Particle reduction is achieved by chewing, partly during feed intake but mainly during rumination (McLeod and Minson 1988) while propulsion depends on the strength of contractions of the rumen and reticulum and on as yet poorly understood mechanisms controlling the movement of contents of the reticulum into and through the omasum. The maximisation of feed intake requiring as it does the rapid passage of feed through the rumen would appear to conflict with the needs of the rumen microbes for adequate time for fermentation. A significant amount of potentially degradable fibre may thus pass out of the rumen and even with additional fermentation occurring in the caecum be wasted in the faeces. In this regard, animals such as the donkey, with no anatomical feature such as the reticulo-omasal orifice to retard passage of digesta, have the capacity to eat relatively more feed than ruminants but to digest less of what they eat (Izraely et al. 1989). The advantage that such animals enjoy when feed is plentiful is of course lost when feed supply is restricted.

The ruminant can to some extent adjust the time available for fermentation by increasing the load of digesta retained in the rumen. It is generally assumed that digesta load is a major factor signalling repletion to the brain. However, when an animal is fully adjusted to change from one diet to another, the digesta load may have adjusted by a factor of as much as two (Weston 1985). This capacity for adjustment is affected by physiological state — the

Table 8. Comparison between buffaloes and cattle of dry matter intake (% BW/day) with diets based mainly on rice straw.[a]

Diet	Buffaloes		Cattle	
	DM	Straw	DM	Straw
Straw : Leucaena (95:5)	1.69	1.69	1.46	1.46
Straw : Urea : Minerals (basal)	1.87	1.87	1.52	1.52
Basal + rice	2.03	1.84	1.52	1.33
Basal + protein meal	2.34	1.96	1.92	1.54
Basal + {protein meal / protected protein meal}	2.33	2.15	1.85	1.67

[a] Kennedy (1989a,b).

Table 9. Comparison between buffaloes (B) and cattle (C) of intake (% BW/day), digestibility, and cotton thread disappearance (%/hour), with four forage diets.[a]

	Intake		Digestibility		Cotton thread	
	B	C	B	C	B	C
Dolichos lablab	1.29	1.35	0.444	0.413	1.66	1.87
Digitaria decumbens (Pangola)	1.26	1.17	0.491	0.507	1.29	1.25
Stylosanthes hamata (Verano)	1.38	1.46	0.458	0.489	1.19	0.87
Sorghum	1.71	1.73	0.595	0.613	1.50	1.46

[a] Kennedy (1989b).

increase in rumen digesta load associated with increased nutrient demands of lactation (Weston and Cantle 1982) contrasts with the restriction in load in late pregnancy as the rumen is compressed by the expanding uterus (Weston et al. 1983). Animals exposed to cold stress increase feed intake by increasing the rate of passage of feed residues from the rumen (Christopherson and Kennedy 1983). The reverse situation applies to the animal exposed to heat stress from the environment and from work (Christopherson and Kennedy 1983). It is difficult to see a mechanism permitting a major increase in feed intake in such animals, despite the similarity in nutrient demands of the lactating animal.

Cattle vs Buffaloes

Adjustment of load in the rumen and of variables associated with the passage of residues from the rumen differs between species. The buffalo, for instance (Kennedy 1989a) when eating 10% more feed than the Zebu cross steer, ruminated 30% longer and probably more effectively, passed feed residues more rapidly from the rumen, and maintained a smaller amount of more finely ground feed residues in the rumen. Indirect evidence suggested that bacterial attack on plant fibre was more rapid in the buffalo but because of reduced time for fermentation, was less effective, and despite the differences in feed intake, similar amounts of fibre were digested by the two species. However, the differences observed in feed intake between the species were not consistent. They tended to be observed with diets based on rice straw (Table 8) but not on better quality forages (Table 9). Pertinent data on chewing activity and rumen fill are not available with all diets at present, so the extent of physical involvement in the intake of those diets is not known. Studies on the rate of removal of cotton thread from dacron bags in the rumen failed to show an expected higher rate of cellulolysis with feeds of better quality but whether this represents the true situation or an artefact is not yet known.

Nitrogen and Sulfur

Feed intake is affected to some extent by fermentative activity, particularly by rumen microbes that weaken forage cell walls and that provide microbial protein for subsequent use by the tissues of the animal. For these reasons the animal must receive amounts of N and sulfur (S) adequate for the needs of rumen microbial population. Siebert and Kennedy (1972) increased the intake of *Heteropogon contortus* by 29% by supplementation of cattle with urea and minerals, while the intake by sheep of *Digitaria pentzii* containing 0.17% S was 36% higher than with similar feed containing 0.11% S (Rees et al. 1982). In the latter, the low S diet failed to support anaerobic rumen fungi (Akin et al. 1983) known to weaken fibre. However, the extent to which supplementation with N acts through an increase in the population of microbes, of specific microbes or of additional protein to the intestines, is not clear. There is evidence that levels of rumen ammonia of 50 mg N/l are adequate to support maximum fibre breakdown, whereas feed intake continues to increase with ammonia levels of 150 mg N/l (Boniface et al. 1986). There is indirect evidence (Morrison et al. 1988) that microbial protein synthesis benefits from the higher levels of ammonia. This suggests that feed intake responses with higher levels of rumen ammonia may be related to an improved supply of protein to the tissues.

These observations raise three issues of importance to draught animals. The first is the significances of higher levels of rumen ammonia usually observed with buffaloes rather than cattle (Kennedy 1989a). It was postulated that this reflected more efficient recycling of N from blood to rumen in buffaloes and should explain the greater feed intake with buffaloes, but supplementation of cattle with urea failed to bridge the gap. There is need for further study of the dynamics of ammonia in the rumen of cattle and buffalo. The second aspect concerns the practical difficulty in maintaining adequate levels of rumen ammonia in animals fed nonprotein N, as there is some evidence that even when cattle consume 100 g of urea/day mixed in molasses, the levels of rumen ammonia may be less than adequate for much of the day. A feeding system incorporating the controlled release of ammonia in the rumen could greatly benefit the animal subsisting on mature forage. The third aspect relates to the additional urea metabolism observed during work (Table 6), and raises the question as to whether the working animal may be favoured by recycling of additional urea to the rumen.

In summary, factors affecting feed intake and digestion are reasonably well understood. There is need for simple methods to diagnose the nutrients limiting these variables to provide a basis for improving the diet of the animal. Equally the need exists to determine the use to which nutrients are put and that is discussed in the next section.

Nutrient Release

Knowledge of nutrient release during the digestion of tropical forages is limited. In a previous review (Lindsay and Hogan 1987) data could be obtained from cattle fed tropical forages of varying digestibility only by extrapolation from guidelines established with sheep (Weston and Hogan 1986). The position has not altered since then. According to these guidelines, about 8.5 moles of volatile fatty acids are produced for each 1 kg digestible organic matter (DOM) intake, with the rates of production of acetate, propionate and butyrate being equivalent to their molar proportions in the mixture. The amount of protein leaving the rumen has been calculated as 0.36 crude protein intake + 0.16 DOM intake which indicate respectively the undigested dietary and microbial components. With some mature tropical diets fed to cattle there are indications that the microbial component is less than indicated here (Hunter and Siebert 1980; Bakrie et al. 1988). To the crude protein leaving the rumen a further component, probably about 20 g/day, is added to account for endogenous protein addition in the abomasum. Amino acids absorbed are assumed to be equivalent to 0.545 crude protein leaving the abomasum (Lindsay et al. 1980). These data permit calculations to be made of the amounts of amino acids relative to energy supplied by the diet. By extrapolation from sheep data (D.G. Armstrong, pers. comm.), long chain fatty acids (LCFA) leaving the abomasum are assumed to be equivalent to (g/day) 10 + 1.1 LCFA intake. The excess over intake represents bacterial LCFA synthesis, but this value may be an underestimate (O'Kelly 1985) with bacteria from Zebu cross cattle and buffaloes. It appear that LCFA absorption from the intestine is equivalent to about 0.75 of the amount leaving the abomasum.

Despite the reservations expressed above, these calculations provide a framework within which to assess the capacity of feeds to meet requirements on the basis of relatively simple measurements. They can be used, by conversion from DOM to digestible energy and thence to ME, to gain access to standard tables on the amounts of a particular feed needed by animals for a given purpose. Similarly they can provide useful information on the adequacy of dietary N to meet the needs for rumen ammonia and intestinally digested protein. In this way they represent a first attempt at diagnosing nutrient deficiencies in a feed and provide a basis for establishing hypotheses for future work. Their main failing, especially with tropical grasses, is their inability to predict feed intake. With temperate grasses intake can be predicted with an error of 10–20% from organic matter digestibility, but the potential errors in this type of prediction are far greater with tropical feeds.

Despite this, the calculations above can be used to calculate the conversion of nutrients released in the digestive tract into glucose, protein and fat, though further, often conflicting assumptions are involved. For instance, whereas Leng (1970) postulated that glucose can be synthesised at 180 g/296 g propionate and 55 g/100 g absorbed amino acids, it has been suggested (Lindsay and Hogan 1987) that more realistic values are 180 g/200 g propionate and 30 g/100 g absorbed amino acids. However, neither set of values was obtained under conditions of severe nutritional stress such as prevails with an underfed lactating or working animal. Similarly, the assumptions of high efficiency of conversion of absorbed amino acids into protein (0.75, ARC 1980) or of acetate and LCFA into fat are based on experiments conducted in circumstances very different from the situations that they are intended to describe.

Responses to supplementary feeding of energy and protein provide the most direct evidence of deficiency of major nutrients in the same way that mineral supplements do. However, they do not necessarily define the limiting specific nutrient. Protein supplementation (Lee et al. 1985) provided increases in roughage intake, and milk output in the cow, increased growth rate in suckled calves, and a change from weight loss to weight gain in the cow. Similarly it may be calculated from supplementation of lactating dairy cows with formaldehyde treated casein (Flores et al. 1979) that the cow synthesised, per kilogram absorbed amino acids, 160 g protein, 187 g fat and 133 g lactose. The implication that amino acids alone achieved all these changes is untenable, but the calculations indicate that supplements can influence many different mechanisms in the undernourished animal.

Body Reserve Nutrients

The calculations discussed above refer only to nutrients released in the digestive tract. They do not take into account the nutrients released from the tissues during weight loss which, within limits, is an acceptable feature of animal management. Knowledge of the composition of weight loss is not very satisfactory. The assumption is generally made that the proportions of protein and fat in lost weight reflect the proportions laid down during weight gain; hence weight loss in young animals would tend to provide relatively more protein and less fat than in older animals. There appears to be no direct information on the extent to which work might influence the composition of gain or loss. If there is little influence, the mature animal should benefit most from weight loss comprising a high proportion of LCFA. The need for the animal to regain body weight during the nonworking season is a further feature of draught animal management. This process in the undernourished animal presumably benefits from compensatory growth. As with normal growth, there is a lack of information about the composition of compensatory gain in the mature animal (O'Donovan 1984) but it again seems to be assumed that the proportion of protein and fat in compensatory gain reflects that in normal gain; if that is so, gain in the mature animal should contain a high proportion of fat and requirements for dietary protein should be correspondingly less than in the younger animal.

Perhaps of more value in studies of weight loss in undernourished animals is the method used by Morris (1968) to calculate the dietary energy equivalent to a given rate of weight loss. This calculation is made by plotting the relationship between ME intake and weight loss. With Hereford and Shorthorn steers of about 180 kg (Fig. 4),

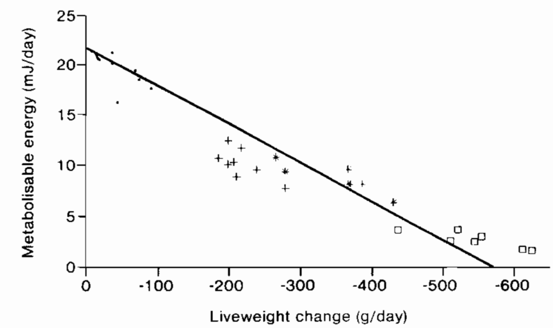

Fig. 4. The relationship between metabolisable energy intake and liveweight loss in Hereford and Shorthorn steers (adapted from Morris 1968).

weight loss of 1 kg/week could theoretically be prevented by supplying an additional 32 mJ ME.

Matching Nutrient Demand and Supply

The problem of matching the nutrient demands of the animal with feed supply depends on management factors such as the age and sex of the animal, the value of a calf and the proportion and time of year during which the animal is required to work. If on small farms supporting one draught animal, the intact cow is preferred over the castrate male, socioeconomic factors such as the need or desirability of producing one calf per year appreciably affect attempts to meet the animal's nutritional needs. Further, the evidence presented above that lactation imposes a similar nutrient demand to work indicates the need to separate those two periods of heavy nutritional demand. If only a short period of postpartum anoestrus is desired, the need to regain weight rapidly after lactation must also be taken into account. Work periods are fixed by climatic and economic factors and the farmer must use management skills and judgment to integrate other physiological events such as pregnancy and lactation.

Regardless of that decision, it is clearly desirable to feed the animal to achieve adaquate weight gains after both lactation and work. With the reproducing cow, this may require the early separation of the calf with attendant problems of nutrition of the young animal. In that connection studies with the Zebu cross calf with birth weight 32 kg and weaned at 50 kg (A.C. Schlink, pers. comm.) indicate that capacity to eat dry matter and needs for energy and protein conforms well with data obtained with European beef breeds of similar size. The nutritional requirements of such animals can therefore be predicted with reasonable accuracy. With both the working and reproducing cow striving to regain weight with a high fat content, supplements containing high levels of lipids, such as rice bran, can be used to advantage (Upadhyay, These Proceedings).

However, the most important source of nutrients will probably continue to be rice straw, supplemented with grasses or pasture or browse legumes. The nutritive value of rice straw will depend on stage of maturity at harvest. Evidence that rice straw plus protein concentrates can provide nutrients well above maintenance (Table 6) suggests that study is warranted on the most appropriate harvest dates. More detailed information is required of the available sources of protein, though it is known that *Stylosanthes hamata* cv *Verano* is similar in protein value to lucerne (*Medicago sativa*) (McSweeney et al. 1988) and that much of the protein in *Leucaena leucocephala* escapes the rumen microbes to be digested in the intestines (Bamualim et al. 1984).

However, it is probable that the full potential of many of these feed sources has not been realised. Recent nylon bag evaluation of 26 accessions of *Gliricidia sepium*, for instance (T. Ibrahim, B. Palmer and A.C. Schlink, unpublished data) indicated a range of 20 units from 0.65 to 0.85 in digestibility; many other legumes have not been evaluated at all. Conversely, however, some types of feed such as rice straw may be reduced in feed value through the efforts of plant breeders trying to transfer the maximum amount of plant nutrients into the grain.

Conclusion

This review has indicated the great progress made in the past decade in understanding the nutrition of the draught animal and equally, the need for a sustained further effort to fill the gaps in our knowledge. The general picture that emerges is of an animal subjected to what appears to be an inadequate, low-quality diet of poor digestibility and low protein content. However, the requirements for work based largely on acetate and the body fats derived from acetate and the corresponding deposition and withdrawal of LCFA from the tissues, are adequately served by the high-acetate fermentation in the rumen. The correspondingly lower requirements for protein in the working animal, coupled possibly with an increased recycling of urea to the rumen again favour the animal offered mature forage provided that a relatively small amount of additional protein is made available. The nonproducing draught animal thus is reasonably well served by its nutritional environment.

However, this situation is likely to change with the increasing interest in the multipurpose animal (e.g. Devendra 1989). This animal will present new nutritional challenges demanding further research not only on energy supply but also on the provision of adequate protein and minerals. To meet these challenges study must be made of improved sources of feed, for example browse legumes, to ensure that the best cultivars become widely used. There is no reason to doubt that plant and animal scientists can combine to provide on a sustained basis the nutrients needed for improved output not only of work but also of milk and meat.

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Improving the Nutrition Level of Draught Animals Using Available Feeds

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Abstract

Although a wide variety of draught animal power enterprises exist they are usually characterised by hot climates and low-quality feeds, and under these conditions draught management practices have naturally evolved to maximise efficiency from available resources. Ruminants are the most efficient draught animals in terms of converting low-quality fibrous feeds into mechanical work.

The extra energy needed for work in traditional draught systems is partially compensated for by physiological changes that increase the availability of endogenous and dietary nutrients, but the efficiency of utilisation of energy may be reduced if the supply of energy-yielding substrates cannot be used directly by the active muscle.

The capacity of animals to do work is largely dependent on the efficiency with which available energy is used. As contracting muscles require specific substrates (glucose and LCFAs), the efficiency of energy utilisation for work is dependent on the supply of preferred nutrients in the feeds, on body reserves, and on the intensity of work. In ruminant animals, an efficient rumen fermentation can supply adequate nutrients to replenish body energy stores provided that there is a sufficient interval of rest between working periods. Rumen undegraded concentrate supplements should be fed to animals during periods of hard work and to pregnant and lactating animals that are required to work.

Introduction

DRAUGHT animal power (DAP) has been an integral part of traditional agricultural systems for thousands of years. About a third of the world's arable land is cultivated by animal power (Ramaswamy 1987). While there may be a tendency towards using mechanised power in response to a need for greater efficiencies in agriculture, draught animals will always continue to play an important role, particularly in intensive agricultural regions of the tropics. Here, the increasing demand for land to cultivate food crops has meant a shift from pasture grazing of livestock to stall feeding with crop residues. Cattle and buffalo are most widely used for cultivation, existing on poor quality feed and working in hot ambient temperatures. Horses are less well adapted to these types of feeds and are used mainly for transport. Under these conditions, draught systems have generally evolved towards maximum efficiency with draught loads averaging 10–15% of animal body weight being endured for 3–6 hours/day (Pathak and Gill 1984; Ffoulkes et al. 1987).

Animals and Feeds Used in Draught Systems

Most rural communities in Asia rely on large ruminants to provide farm power. The availability of feed for the animals is dependent on the abundance of natural forages found at the borders of cultivated areas and road verges and on the

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seasonality of regional cropping systems. There are also large unexploited reserves of mixed grasses under plantation crops but these are usually located far from the main populations of draught animals. In the Philippines, harvest residues of upland food crops such as maize supplied half the animal's diet for 6 months of the year. In sugar-growing areas, cane tops were the predominant feed source during the cane harvest in the dry season, replacing natural herbage that was abundant during the rest of the year (Moog 1986). Petheram et al. (1985) reported that in West Java, Indonesia, buffaloes were preferred for preparing rice lands because of the heavier soils and wetter conditions, and worked for up to 200 days/year depending on the number of crop cycles/annum and the rental market. Cattle were generally preferred for cultivating the lighter soils of upland or drier areas where maize was mainly grown as a single annual crop. The cattle might only be worked in the fields for 30 days during the cropping season but were occasionally employed for road haulage at other times of the year. It was estimated that about 25% of the rice straw and 75% of the maize stover remaining after the harvest was used for feeding livestock (Jan Nari 1986). Seasonal forage components (fresh basis) of draught animal diets sampled from Javanese villages ranged from: grasses (10–40%), green rice straw (4–60%), maize stover (5–35%), cassava tops (5–10%), legume leaves (1–15%), tree leaves (3–10%), mixed weeds and herbs (2–10%), banana leaves (1–3%), and bamboo leaves (2–5%) (Petheram et al. 1985; Little et al. 1988).

In other parts of Asia, DAP enterprises are managed similarly within their specific farm systems. The practice of herding draught animals in Thailand closely follows a seasonal pattern and when pasture resources are not available towards the end of the dry season, farmers rely on stored rice straw to provide the bulk of the feed (Wanapat 1985). On the Indian subcontinent, pastures are no longer a major feed source and can be used only as a supplement to feeding crop residues. India has the largest population of draught animals (85% are cattle) with most of the power requirements for agriculture being provided by animals working between 45 and 230 days/year depending on the size of farm (Pathak and Gill 1984; Ramaswamy 1987). In China, yellow cattle, buffalo and crossbred yaks may provide 50% of power for cultivation (Ramaswamy 1987); purebred yaks are used as pack animals and horses are favoured for pulling carts (Feng Yang-lian 1984).

In sub-Saharan Africa, oxen are the predominant draught animal, preparing some 5–10% of total arable lands sown to annual crops (Anderson 1985), of which maize, millet and sorghum produce the greatest tonnage of residue (Butterworth and Mosi 1985). However, as there is generally sufficient land available for grazing livestock a substantial part of their diet is from pasture. Camels and donkeys are used in smaller numbers in more arid regions (Pathak and Gill 1984). In Tropical America, cattle are also important for draught and are fed residues from corn, sorghum and wheat, and supplemented with agroindustrial wastes such as corn cobs and cotton seed hulls (Parra and Escobar 1985). In the high Andes of South America, llamas and alpacas are used to carry loads of 35–50 kg (about 35% of liveweight), feeding on lichens, mosses and hardy mountain grasses, and in the subarctic regions, moose and reindeer are used for pulling sledges and pack work (McKenzie 1974).

Nutrition of Working Animals

Metabolism of Active Muscle

Working muscles need a continuous supply of energy-yielding substrate to provide high energy phosphate (ATP) for sustained muscular activity. These aspects were reviewed by Leng (1985), Pearson (1985), and Preston and Leng (1987). Contracting muscles at low intensities of work are probably sustained by the faster flow of blood nutrients absorbed directly from the diet, but as these become exhausted fat and glycogen stores in the body are mobilised to meet continuous energy demand. Exhausted metabolites are replenished during resting periods.

It appears that the higher rate of metabolism of the working animal is not confined to the period of active work. Lawrence and Campbell (1987) report that the basal metabolic rates of oxen on a low level of feeding were 8–12% higher during resting periods on working days. This may be the cause or effect of elevated body temperature of animals recovering from work.

Effect of Work on Digestion

The effect of work has been shown to alter digestive function in horses (Olsson and Ruudvere 1955; Orton et al. 1985a) and in buffaloes (Ffoulkes et al. 1987), resulting in increased availability of feed energy. This was apparently due to better feed digestibility, longer residence times of digesta in the gut and/or higher feed intakes (Upadhyay et al.

1983; Orton et al. 1985a; Ffoulkes et al. 1987). These findings are not consistent with other studies (Lawrence 1985; Bamualim et al. 1987; Bakrie et al. 1988; Bamualim and Ffoulkes 1988; Wachirapakorn and Wanapat 1988; Merritt and Pearson 1989), although higher feed intakes in working buffaloes were recorded by Wachirapakorn and Wanapat (1988). These inconsistencies could be due to different experimental conditions (i.e. condition of animal, intensity of work, level of feeding, interval of measurement of digestion parameters, etc.).

At high ambient temperatures, animals attempt to lower their heat load by reducing feed intake (Young 1982). Working animals with elevated body heat loads from both metabolic and environmental origin would also be expected to have reduced appetites. As feeding level decreases there tends to be an increase in digestibility of feed (Schneider and Flatt 1975) or metabolisability of feed energy (ARC 1980).

A study by Bamualim and Ffoulkes (1988) considered that feed availability might be a constraint under village conditions, so they fed restricted and ad libitum quantities of a traditional diet consisting of rice straw/mixed native grasses (50:50) to nonworking buffalo and to buffalo working in a simulated draught system. All animals were in medium body condition at the start of the trial. Over a 3-month period there was no effect of work on feed intake at either feed level, but the working animals on restricted rations forfeited less growth than their working counterparts that were fed to appetite. If the energy of potential growth is related to the energy cost of work then the buffaloes on the restricted diet appeared to have a lower energy requirement for the same work. A possible explanation for this is that while there was an increase in energy intake from the diet this was not accompanied by an increase in the availability of preferred substrates, giving rise to inefficient metabolic pathways and additional heat production.

Equines vs Ruminants and Cattle vs Buffalo

The horse is superior to the ruminant in thermoregulatory control of body heat load and in meeting the immediate requirements of exercised muscle (Pearson 1985); however, ruminants are able to utilise fibrous feeds more efficiently than horses as a source of nutrients for working muscle.

The foregut (rumen) of the ruminant animal is colonised by billions of microorganisms which break down ingested feed by fermentative digestion and proliferate from the synthesis of nutrients released in the fermentation process. The waste products of rumen fermentation include volatile fatty acids (acetate, propionate and butyrate) which are absorbed from the rumen and used by the animal as major sources of oxidative energy and for glucose synthesis (from propionate) and lipogenesis. The microbial cells which are high in protein are carried with the digesta into the small intestine where they are digested by gastric juices. The resulting amino acids are used for body tissue repair and growth, and as a source of glucogenic energy when this is in heavy demand.

In contrast, the site of fermentation in the horse is in the hind gut which receives the products of gastric digestion from the stomach and small intestine. The fermentative process is much less extensive than in ruminants, and furthermore, the microbial population does not contribute significantly to the protein requirements of the horse. This means that equines are more dependent on dietary sources of protein and energy, and require high energy diets to endure long periods of exercise.

It has been widely reported that of the two major ruminant species used for draught power, the buffalo is able to utilise low-protein fibrous feeds better than cattle (Anon. 1981). Studies in Australia show that buffaloes fed low-protein roughages were better able to maintain an efficient rumen fermentation than cattle, and this was associated with longer rumination times, enhanced urea recycling and higher rates of passage of digesta in the buffaloes (Kennedy et al. 1987a, b; Kennedy and Waterhouse 1987; McSweeney and Kennedy 1987).

Requirement for Energy

The capacity of animals to do work is largely dependent on the availability of feed energy and the efficiency with which it is used. Until recently, few studies had examined the energy requirements of working ruminants whereas the nutrient requirements of working horses have been studied in detail (NRC 1978). The extra energy requirements over maintenance for working cattle and buffalo were summarised from various sources by Bamualim and Kartiarso (1985). Lawrence (1985, 1987) has quantitatively estimated the energy requirements of ruminant draught animals by incorporating empirical values of energy expenditure for different types of work into the British Metabolizable Energy (ME) system (MAFF 1975; ARC 1980). At this stage considerably more baseline data need to be collected in the light of the different physiological responses to a range of working and body weight conditions. However, meeting these energy demands depends on the preferential requirement for particular energy-yielding substances, and their availability is likely to be closely associated with the efficiency of energy utilisation for work.

Metabolic studies on exercised muscles of ruminants indicate that of all the energy-yielding substrates taken up by active muscle, glucose and long chain fatty acids (LCFA) appear to be critical nutrients for sustained muscular activity (Leng 1985). These substrates, or their precursors, are therefore the major requirements of draught animals during the working period and during periods of rest when body stores of fat and glycogen are being replenished. Furthermore, they are critical nutrients for growth, pregnancy and milk production.

A major source of LCFAs is dietary, but when the diet is conducive to a high acetate fermentation in ruminants (i.e. such as low protein fibrous crop residues), LCFAs are likely to be synthesised from the excess acetate (see Preston and Leng 1987). Very little glucose is absorbed from the gut with unsupplemented ruminant diets based on fibrous feeds. Glucose is mostly synthesised from propionate and to a smaller extent from amino acids. Apart from being a major intermediate energy source for metabolic processes throughout the body, glucose has an obligatory function in synthesis of fatty acids which are required for work, growth and lactation.

Requirement for Protein

Lawrence (1985) reported that there were no significant differences in the nitrogen balance of working oxen with an energy requirement of 1.5 × maintenance; however, Graham (1985) suggested that draught work performed under hot conditions would result in an increase in protein catabolism. Furthermore, if glucose supply is limiting for productive functions, protein may be used for glucogenesis.

Orton et al. (1985b) found that exercised horses fed a low protein diet grew faster than those not exercised, and concluded that exercise had created an outlet for unwanted energy and better metabolic conditions for tissue growth. Similar responses were reported by Merritt and Pearson (1989). In their study, donkeys fed hay gained liveweight at twice the rate when walked daily compared with their resting counterparts (476 vs 238 g/day), but both treatment groups lost weight at the same rate (−774 g/day) on a lower quality straw.

Requirement for Minerals

Under normal working conditions ruminants are not likely to require extra minerals other than those recommended by feeding standards (NRC 1976; ARC 1980; McDowell et al. 1983). However, as the intensity of work causes sweating, particularly in cattle, salt losses will need to be replenished. Horses under heavy endurance can lose through sweating up to 50 g/day of salt together with other electrolytes.

Nutritive Value and Utilisation of Feeds

Feed Evaluation

The nutritional value of feed lies in its ability to provide nutrients to meet the animal's requirements for various physiological functions such as work. The animals themselves are the best judge of feed quality if allowed to selectively graze or browse, but ultimately the availability of nutrients depends on the chemical nature of the feedstuff and the degree to which the nutrients are released by digestion. Chemical analyses and feed digestibility are therefore used to predict the value of feeds and these are presented in Table 1 for a range of feedstuffs used in DAP enterprises.

The nutritive value of feeds for ruminants depends on the supply and balance of nutrients to maximise fermentative digestion by the foregut microorganisms, and on the availability of extra dietary nutrients in the intestine. In temperate regions, livestock feeding systems are generally based on highly digestible forages and cereal grains which provide an abundant array of nutrients at both sites of digestion in the ruminant gut. The problem with most feeds used in traditional draught systems is that they are generally low in digestibility and have a poor balance of nutrients. This gives rise to a slow and inefficient rumen fermentation, and therefore a poor supply of energy-yielding substrate to the animal. However, these imbalances can be rectified to improve feed utilisation by incorporating into the ration other feed types with known partitioning of nutrients at the different sites of digestion. A systematic approach to feed evaluation was presented by Ffoulkes (1986a) and Preston and Leng (1987) which broadly categorises feeds into the

Table 1. Composition and digestibility of feeds (DM basis) commonly available in DAP enterprises (preferred values taken from various sources).

	DM (%)	CP (%)	CF (%)	Fat (%)	Mineral composition (g/kg DM) Ca	P	Na	S	DMD (%)
Crop residues:									
Rice straw	33–95	4–6	33	1	5	2	1	1	38–55
Maize stover	85	6	32–46	1	4	2	0	2	54
Sorghum straw	91	4–8	33	2	3	2	1	–	42–48[b]
Sugarcane tops	28	6	35	2	5	2	1	4	62
Bagasse	44–55	1	43	1	5	3	–	3	33[b]
Cassava leaves	26	20	21	4	20	3	1	2	72[a]
Banana leaves	24	12	23	4	7	3	1	2	45–66
Sweet potato forage	11	13	14	4	14	3	<1	3	93[a]
Native grasses:									
Indonesia	22–26	6–9	34	(2–5)	5	2	<1	2	38–52[a,b]
Malaysia	23	10	26	–	12	4	–	–	–
Tree legumes:									
Leucaena	30	29	21	4	16	3	1	4	51–60[a,c]
Glyricidia	27	24	18	4	7	2	1	3	67[a,c]
Concentrates:									
Rice grain	86	10	10	2	1	3	1	–	63–95[a]
Rice bran	86	10	20	11–22	1	18	1	2	43[a]
Maize grain	86	10	2	5	0	3	1	1	65[a]
Soya bean meal	90	37–48	5	4	3	6	<1	3	25[a]
Kapok seed meal[d]	90	31	30	8	5	13	–	–	50[a]
Cotton seed meal[d]	86	44	14	8	4	11	–	–	28–50[a]
Copra cake	90	22	15	6–10	12	1	1	2	62[a]
Molasses	75	4	0	0	11	1	2	9	100[a]
Tapioca waste	90	2	3	4	6	2	1	–	69[a]
Palm kernel cake	89	19	13	5	3	7	<1	2	–

DM (Dry matter), CP (Crude protein), CF (Crude fibre), OM (Organic matter), DMD (Dry matter digestibility)
[a] Rumen degradation over 24 hours by in sacco technique.
[b] in vitro digestibility. [c] Goats. [d] Expeller.

following dietary components (Table 2):

- Basal diets that are fed ad libitum to provide the bulk of fermentable energy (from structural carbohydrates), nitrogen and essential mineral elements needed for optimum microbial growth in the rumen and production of energy-yielding substrate.
- Feed supplements or substitutes that are degraded in the rumen releasing nutrients which balance the requirements of the rumen microorganisms.
- Rumen undegraded feed supplements (also known as escape or bypass supplements) that are resistant to microbial digestion but release extra nutrients (protein, starch and fats) in the small intestine which can be used directly by the animal for specific physiological functions such as work.

Basal diets

The structural carbohydrates of roughages are generally a good source of fermentable energy, but the rate of release of energy depends largely on the balance of other nutrients in the rumen. Most crop residues such as rice straw, maize stover and sugar cane tops are used as basal feeds but are regarded as poor quality because of insufficient nitrogen and sulfur sources.

A good indication of quality of a basal diet is dry matter loss from intraruminal bags over 24 hours (Mehrez and Orskov 1977; Ffoulkes 1986b). Broadly speaking, basal diets with dry matter losses of 55–65% will support draught work and some production. Feeds with dry matter losses of 40–55% can maintain the working animal, but supplementation is needed to achieve the same level of productivity. Below this range, the diet is not likely to provide sufficient nutrients to maintain the working animal.

Studies with rice straw indicate that physical treatment (chaffing, soaking in water, etc.), application of chemicals, or supplementation with

Table 2. Systematic approach to feed evaluation (Ffoulkes 1986a).

	STEP 1
OBJECTIVE :	Identify potentially useful nutrients.
METHODS :	Chemical analysis of major components (organic matter, nitrogen, neutral detergent fibre sulfur).
	STEP 2
OBJECTIVE :	Classify into potential ration components.
METHODS :	In vitro digestibility (Tilley and Terry 1963). Digestion rate and potential digestibility by intraruminal bags (Ffoulkes 1986b; Mehrez and Orskov 1977). Solubility (McDonald and Hall 1957).
	STEP 3
OBJECTIVE :	Test quality of feedstuff as ration component.
METHOD :	Rumen level
	1. Basal diet — in vivo digestibility, voluntary consumption, analysis of rumen fluid metabolites (Ffoulkes 1986d; Preston and Leng 1987).
	2. Rumen degraded supplements — as for basal diets.
	Intestinal level
	3. Rumen undegraded supplements — production trials (growth, milk) that give response curves.
	STEP 4
OBJECTIVE :	Comprehensive documentation of results.
METHODS :	Tabulate results according to systematic evaluation processes.

green forage or concentrates, are generally necessary to maintain nonworking ruminant livestock (Doyle et al. 1986). Pearce (1986) pointed out that a major factor affecting the feed value of rice straw is its variable digestibility and this was related to rice variety, cropping management, degree of senescence at harvest, and cutting height. In practice farmers supplement rice straw diets by cutting green forages for stall-fed animals or by allowing the animals to graze. In studies on draught buffalo working 3 hours/day for 3 months, growth rates of between -348 and 107 g/day (average -104 g/day) were recorded on ad libitum diets consisting of 50:50 mixtures of green straw and native grasses (Bamualim et al. 1987; Bamualim and Ffoulkes 1988; and Bamualim and Ffoulkes, unpublished data). As the work program was the same in each study the wide range in growth rates was indicative of seasonal variation in the quality of the forages. In the village situation in West Java where draught buffalo are fed diets consisting mainly of fresh rice straw, average daily liveweight gains declined from 230 to 50 g/day in relation to increasing liveweight (Bamualim et al. 1988).

Feeding systems based on sugarcane and its byproducts were reviewed by Ffoulkes (1986c). Working oxen in Pakistan maintained weight on a diet of sugarcane tops (Preston and Leng 1987) and good growth rates in nonworking cattle were obtained with sugarcane tops that were supplemented with urea and concentrated feedstuffs such as rice and copra meal (Ferreiro and Preston 1976; Roxas 1984).

Molasses-based diets are commonly fed to ruminant livestock in Central America. These diets require a small amount of roughage and additional fermentable nitrogen (usually in the form of urea at a rate of 30 g/kg molasses) and a small amount of roughage to maintain the nonworking animal (Ffoulkes 1986c).

Rumen Degraded Feed Supplements or Substitutes

The production of energy-yielding substrate from the end products of rumen fermentation is generally impaired by nutrient deficiencies in the basal diets. The primary nutrient deficiency in the rumen is nitrogen and this is often reflected in low rumen ammonia levels. It is contended that ammonia levels of between 20 and 190 mg NH_3 -N/l of rumen fluid are adequate for optimal microbial growth (Hume 1970; Ramirez and Kowalczyk 1971; Miller 1973; Satter and Slyter 1974), and that cellulose digestion and feed intakes increase with increasing levels of rumen ammonia (Krebs and Leng 1984; Boniface et al. 1986). The consolidated results of many reports summarised by the ARC (1980) indicate that rumen microorganisms require 30 g nitrogen/kg of organic matter apparently digested in the rumen (i.e. 65% of total digestible organic matter — DOM), or for more practical purposes, 20 g nitrogen/kg DOM.

Sources of fermentable nitrogen are wide ranging but the most common resource in village draught systems is the mixed native grasses (Table 1) which often include legumes and weeds. The protein fractions of some of these forages appear to be rapidly fermented in the rumen resulting in very high levels of ammonia in rumen fluid (250-300 mg NH_3 -N/l) in sheep (Ffoulkes 1986a). When equal proportions of mixed native grasses and fresh rice

Table 3. Degradation of high protein forages in cattle fed sugarcane-based diets (Minor and Hovell 1979).

Forage	N content (%)	Digestibility in 24 hours (%)	
		DM	N
Leucaena	3.5	51	54
Cassava	3.0	72	56
Sweet potato	3.4	93	95
Banana	2.6	28	44

straw were fed to cattle or buffalo, rumen ammonia levels were 93 and 167 mg NH_3 -N/l respectively (Winugroho, Sutjipto and Ffoulkes, unpublished data; Bamualim 1989).

The tree legumes are another source of fermentable nitrogen at the village level (Table 1). Their utilisation as feed supplements was reviewed by Doyle et al. (1986) and Elliot (1987). These high protein forages are able to provide extra feed protein in the small intestine as well as contributing to the nitrogen status of the rumen. Moreover, they appear to stimulate the growth of rumen fungi which break up the lignified cell walls of fibrous plant material. Addition of leucaena forage to a low protein fibrous diet significantly elevated rumen ammonia levels in goats while also increasing DOM intake and microbial protein synthesis (Bamualim et al. 1984). Other studies report increases in feed efficiency with supplements of legume even though substitution effects were also evident (Bamualim 1986; Elliot 1987). These responses seem to be optimal when the legume forage is 20–30% of the diet (Preston and Leng 1987); however, toxic substances that are present in some legume species may cause disease symptoms if high levels of the forage are fed to livestock (Hegarty et al. 1986).

Green forages vary in their resistance to microbial degradation and subsequent release of nitrogen in the rumen. This in turn affects the stability of the fermentation process and the availability of protein in the hind gut. This was clearly demonstated by Aii and Stobbs (1980) who compared degradation rates of protein in the legumes leucaena (30% in 24 hours) and *Desmodium intortum* (5% in 24 hours). They suggested that whereas the plant proteins of leucaena were digested in both the foregut and the hind gut, the proteins of *D. intortum* were probably protected from degradation in the rumen and to a large extent were likely to pass undigested through the lower gut as well.

Green forage from food crops such as cassava, sweet potato, and banana leaves are also important supplements for balancing nitrogen deficiencies in the rumen. This is evident from the comparative rates of nitrogen degradation in the rumen (shown in Table 3) where cassava forage proteins are only partially degraded and rank closely with the tree legume leucaena, whereas sweet potato proteins are rapidly digested in contrast to banana leaves which are only slowly digested.

An inexpensive nonprotein nitrogen (NPN) source of fermentable nitrogen is fertiliser grade urea which can be used to supplement a wide range of basal diets, such as cereal straws and sugarcane byproducts (Preston and Willis 1974; Doyle et al. 1986; Ffoulkes 1986c; Preston and Leng 1987). There are various prefeeding treatments that can enhance the effectiveness of urea in straw-based diets. These methods include soaking the straw in alkali or ensiling with urea (Sundstol and Owen 1984). A source of sulfur is also required for microbial protein synthesis when urea is the main nitrogen source in low protein fibrous diets. However, extra sulfur is not necessary on molasses-based diets because of the high sulfur levels in molasses.

The addition of urea to straw-based diets can in theory double the availability of protein, LCFA and glucose synthesis potential in ruminant animals (Preston and Leng 1987). However, the use of urea in livestock feeds is not widespread in the traditional draught enterprise because of its priority role as a fertiliser and because of the known toxicity risks to livestock. In this respect, chicken manure and animal urine are alternative natural sources of NPN which increase feed efficiency when added to molasses/sugarcane tops (Meyreles and Preston 1980, 1982) and straw-based diets (Mahyuddin 1982; Davis et al. 1983).

Rumen Undegraded Feed Supplements

The end products of fermentation of well balanced basal diets are likely to be sufficient to sustain the nutrient requirements of animals working in traditional draught systems. However, at higher intensities of work, the rate of supply of these nutrients is not fast enough and the animal draws on its body fat reserves to meet the extra energy requirements.

The depletion of body reserves can be alleviated by supplementing with feedstuffs of low rumen degradation and which provide extra glucose and fat to the animal. Examples of these are the high protein and oil concentrates such as cotton and kapok seed meals, copra meal and oil seeds, and high energy concentrates such as rice and maize grain or their milling byproducts (see Table 1).

A series of comparative growth trials was carried out in Indonesia with nonworking and working buffaloes using simulated traditional draught systems as a model. In one of the studies (Bamualim and Ffoulkes; unpublished data), there was a parallel linear response in liveweight gain to different levels of rice bran supplementing the basal diet of rice straw and mixed native grasses (50:50). In another trial, the forfeiture of growth by working animals was less by half when isonitrogenous quantities of kapok seed meal were used instead of rice bran. The results of these two studies are shown in Fig. 1. The different responses between

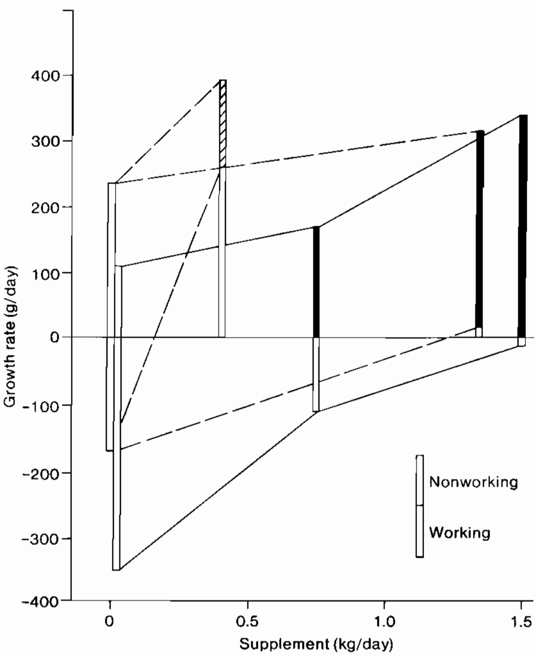

Fig. 1. Schematic representation of effect of supplements of rice bran (▀) and kapok seed meal (▨) on growth rates of nonworking and working buffaloes fed a basal diet of fresh rice straw and mixed native grasses (50:50) in separate studies by Bamualim (1989) (---) and Bamualim and Ffoulkes (unpublished data) (——).

supplements probably reflect the extent of degradation of the feedstuff in the rumen and availability and balance of preferred nutrients in the intestine. Thai workers have also reported higher liveweight gains and rates of work in buffalo when basal straw/grass diets were supplemented with energy concentrates (Konanta et al. 1984).

A primary cause of fertility problems in female draught animals is thermal heat stress combined with poor nutrition (Jainudeen 1985). The effect of nutrition was illustrated in two experiments (Bamualim et al. 1987; Bamualim 1989) in which plasma concentrations of progesterone were measured in working and nonworking buffalo cows. There were 9 vs 18 cows showing positive and 9 vs 2 showing negative ovarian activity respectively. When this diet was restricted to 75% of voluntary intake, ovarian activity was reduced from 4 to 2 positive and from 2 to 5 negative results, respectively.

Female draught animals in the reproductive state require extra nutrients above that supplied from an efficient rumen fermentation, and Preston and Leng (1987) speculated on these requirements. The need for extra nutrients during pregnancy is not high until the last trimester, when the demand for glucogenic energy is increased. In practice, this can be met by supplementing with rumen undegraded feedstuffs of high protein or starch content. The lactating animal, however, has a large demand for extra protein and energy from the diet. LCFAs are needed in both muscle metabolism and in milk secretion. Glucose, which is a major substrate for milk production, only becomes quantitatively important as an energy source for heavy work and acetate is preferentially metabolised in the mammary gland. Proteins are not used to any great extent by the working muscle under normal draught conditions but they could become deficient for milk production if used to synthesise glucose. To maintain milk production in working female draught animals, farmers should feed supplements which increase the availability of glucose and provide LCFAs to the animals.

Feed Management Strategies

Inconsistency of Diet and Frequency of Feeding

Different microbial species are adapted to different feeds and rumen conditions. If the composition of feed is constantly changing then unstable conditions in the rumen will occur resulting in an inefficient fermentation process. Dietary constituents should therefore be changed as little as possible, or at least changed gradually to allow time for the rumen ecosystem to adapt and stabilise.

Stability of the rumen ecosystem is also maintained by frequent feeding of stall-fed animals. When animals are offered feed only once daily, nutrient supply to the microbes is likely to become exhausted in the period before the next feed, resulting in lysis of microbes and a slower rumen fermentation. These conditions are compounded by the animal's ability to select the choicest parts of the diet first and to go without eating less digestible plant fractions such as stemmy material in anticipation of receiving fresh feed the following day.

Importance of Grazing and Browsing

When given the opportunity to graze or browse, animals tend to select feeds that are likely to enhance rumen fermentation. In most draught systems, limited grazing of stall-fed animals occurs during the wet season when green forage is relatively plentiful. In the dry season, however, this may not always be possible and thus it is important to maintain a source of browse, for example, tree legumes.

Feeding Strategies for Draught Work

Ideally, draught animals should be in good condition with adequate fat stores to work efficiently. Cultivation of land in seasonal cropping systems occurs at the end of the dry season when animals are in poorest condition from feeding on low-quality, straw-based diets. Feeding strategies prior to the working season should therefore be aimed at increasing the efficiency of the rumen fermentation process so that sufficient nutrients can be generated to build up stores of body fat and restore body condition. A source of fermentable nitrogen is usually required to correct deficiencies in the basal diet.

Animals that are used for draught in all-year-round cropping systems have only relatively short resting periods between working days and only partial replenishment of fat stores usually takes place. Under these circumstances, animals should be fed to avoid weight losses by ensuring that the basal diet provides sufficient nutrients to maintain the animal's liveweight. However, in circumstances where working animals are in poor condition and cannot maintain body weight, or are subjected to periods of hard work, or are in a productive state, then discrete supplementation with rumen-undegradable concentrates is recommended.

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Supplementary Feeds: Their Effects on Performance of Draught Animals and Their Acceptability to Southeast Asian Farmers

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Abstract

Draught buffaloes and cattle are important to the farming systems of the smallholder farmers of Southeast Asia. Improved management of draught buffaloes during the dry season, or prior to the working season, increases their draught capability and reproductive performance, and enhances the economics of buffalo production. Nevertheless, seasonally available feedstuffs, tree fodder and shrubs, and particularly crop residues, are of the utmost importance. Supplementary feeds should be offered to draught buffaloes/cattle to establish suitable rumen ecology and to maintain body condition during the dry season. The benefits of feeding draught buffaloes/cattle with crop residue-based diets were quickly acknowledged by the smallholder farmers, and the technique was received with great interest.

Introduction

BUFFALOES and cattle are the two major species used for draught power by Southeast Asian smallholder farmers. Their draught capacity has contributed to the success and efficiency of the overall farming systems, particularly in the rainfed areas. A number of factors affect draught capacity of the animals.

Most water buffalo and cattle are raised by 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). Traditional management practices are discussed in Wanapat (1985). A number of feed resources are being used by farmers to feed livestock throughout the year according to their availability and accessibility (Table 1). It is evident that naturally available feed resources and crop residues, particularly during the dry season, are of major importance. However, the limited quantity and quality of feeds and crop residues in the dry season result in low performance in terms of growth, draught and reproductive efficiency.

Feeding Strategies Based on Crop Residues

As stated earlier, draught animals depend on natural feedstuffs and seasonal crop residues. However, the abundantly available crop residues are low in essential nutrients, especially crude protein, Ca, P and digestible energy (Wanapat 1986). As pointed out by Preston and Leng (1984), the development of appropriate feeding systems for draught animal power has received little attention during the past decade. It was therefore suggested that much more detailed information is needed on the digestive physiology of working animals, and the effects of increasing nutritive value (either by treatment of the basal feed resource or through appropriate supplementation). Urea treatment of rice straw has been the most successful chemical treatment for developing countries (Jayasuriya 1983; Wanapat 1985, 1986, 1987; Sundstol et al. 1987). A preliminary experiment conducted by

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Table 1. Sources of feedstuffs, feeding practices and their nutritive value.

Source of feedstuffs/crop residues/ wastes/by-products	Seasonality	Location	Feeding practice	Nutritive value
Native grasses	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	Average–good
Rice straws	Dry, Rainy	Rice-threshing floor Paddy field storage Homestead storage	Self-feeding Hand-feeding	Low
Rice stubbles	Dry	Paddy field	Free-grazing	Low
Corn stovers	Rainy, Dry	Field, Homestead	Cut-carry, grazing	Low–average
Corn cobs	Rainy, Dry	Field, Homestead	Cut-carry, grazing	Low–average
Corn husks	Rainy, Dry	Field, Homestead	Cut-carry, grazing	Low–average
Cassava chip wastes	Dry	Field	Free-grazing Hand-feeding	Good
Cassava leaves	Dry	Field	Hand-feeding	Good
Rice seedling tops	Rainy	Paddy field	Hand-feeding	Good
Peanut crop residues	Dry	Field	Hand-feeding	Average
Cowpea crop residue	Dry	Field, Homestead	Cut-carry, grazing Hand-feeding	Good–excellent
Other leguminous crop residues			Cut-carry, grazing Hand-feeding	Good–excellent Good–excellent
Water hyacinth leaves, stems	Dry Rainy	Homestead Pond	Hand-feeding Free-grazing	Average–good Good
Shrubs and browses	Dry-Rainy	Upland Public area Roadside	Free-grazing	Low–average

(Modified from Wanapat 1985).

Wanapat and Wachirapakorn (1987) revealed that there were only slight decreases in digestible dry matter and organic matter intakes by walking buffaloes as compared to at-rest ones. Ffoulkes et al. (1986) reported that in nonpregnant female buffaloes, dry matter (DM) intake and DM digestibility were significantly enhanced by work compared to at-rest periods when given a diet of fresh field grass and rice straw (1:1) ad libitum (Table 2). However, in a second experiment by Bamualim and Ffoulkes (1987) work did not affect DM intake or DM digestibility, but liveweight was significantly reduced. It was suggested the different response in the second experiment may have been associated with a shorter working time (2 and 3 hours/day) in the work treatment or to longer adaptation periods.

In a trial where feed supplements were given to working and nonworking buffaloes (Konanta et al. 1986), supplementation resulted in an increase in liveweight gain and ploughing ability (Table 3). Additional nutrients provided to the animals as supplements were used for both liveweight gain and for work energy.

The work by Soller et al. (1986) also indicated that work had no significant effects on digestibilities or nitrogen balance. Due to a decline in intake during working of oxen, it was suggested that draught oxen need to be in good condition before ploughing starts. In a similar experiment where buffaloes were fed with untreated or urea-treated rice straw, and treatments of walking and at-rest imposed, DM intakes and digestibilities were found to be similar (Wanapat and Wachirapakorn 1987).

Senakas and Neric (1988) reported that energy intake and expenditure were higher in buffaloes working for 6 hours/day as compared to 4 hours/ day. In addition, the Murrah crossbreds tended to lose body weight much more than the native Philippine carabao when workloads were imposed.

In an experiment conducted by Wachirapakorn and Wanapat (1989a, b) to study the effects of nutrition on body condition prior to working in respect to voluntary feed intake, digestibility and draught capability of swamp buffaloes, the details are as follows. Four castrated male buffaloes with initial weight of 477.3 ± 20.5 kg were randomly allotted in a 2 × 2 factorial arrangement according

Table 2. The effect of work on voluntary intake and digestibility.

Item	No work	Work	± SE	Probability
Expt I				
DM intake, kg/day	8.2	8.8	0.2	(-)
DM digestibility, %	47	53	1.6	*
Expt II				
DM intake, kg/day	8.5	8.2	0.2	NS
DM digestibility, %	40	39	1.0	NS
Liveweight gain, g/day	229	107	20	**

NS, not significant; (-) $P<0.10$; *$P<0.05$; **$P<0.01$
(Expt I, Ffoulkes et al. 1986).
(Expt II, Bamualim and Ffoulkes 1987).

Table 3. Effects of supplements and/or work on liveweight change of buffaloes.

	Crossbred Murrah				Swamp			
	No supp.		Supp.		No supp.		Supp.	
Measurements	W	NW	W	NW	W	NW	W	NW
Initial liveweight, kg	244	321	289	277	289	267	293	285
Final liveweight, kg	312	371	330	350	303	312	333	353
Liveweight gain, g/day	99[a]	281[b]	226[b]	408[c]	75[a]	254[b]	221[b]	384[c]
Ploughing capacity, ha/head/hour	0.036[a]	-	0.036[a]	-	0.038[a]	-	0.048[b]	-
Rate of ploughing, m/min	41[a]	-	48[a]	-	44[a]	-	53[a]	-

Mean with different superscripts differ significantly ($P<0.05$). W, work; NW, no work. (Konanta et al. 1986).

to a 4 × 4 Latin square. The factors employed were dietary factors which included high (H) or low (L) plane of nutrition and draught factors which included working (W) or at rest (NW).

Buffaloes receiving low plane of nutrition were offered rice straw ad libitum but when receiving high plane of nutrition, 2.3 kg DM of concentrate/head/day was supplemented and fed twice daily prior to working period for 4 weeks. During the working period, all animals were offered chopped fresh field grasses and rice straw at 1:1 ration (as fed basis), and fed twice daily. The animals were kept in individual pens during resting period, and were used in ploughing sandy soil during working periods for 2 hours/day for 3 weeks. After ploughing, all animals were watered down to dissipate the generated heat. During the working period, total voluntary dry matter intake (VDMI) was affected by work and plane of nutrition prior to the working period. Total VDMI was significantly increased ($P<.05$) by work from 73.6 to 77.9 g/kg $W^{.75}$/day and by plane of nutrition from 73.1 to 78.4 g/kg $W^{.75}$/day, respectively. However, digestion coefficients of all components were not different ($P>.05$).

Buffaloes fed with high plane of nutrition prior to working period could plough at a faster rate ($P<.05$) on the sandy soil than those fed on low plane of nutrition, ploughing rates being 858.8 and 781.5 m^2 respectively (Tables 4–6). Ruminal pH, ammonia-nitrogen (NH_3-N) and total volatile fatty acids (TVFA) production patterns were similar in the working and at-rest buffaloes. But the mean of NH_3-N concentration in the rumen of working buffaloes (26.7 mg/l) was significantly higher ($P<.075$) than those of at-rest buffaloes (17.0 mg/l) and the TVFA production in the rumen of working buffaloes was also slightly higher but not statistically significant ($P>.075$). The peaks of TVFAs were 83.1 and 74.2 mmole/l at 4 and 2 hours postfeeding for the working and the at-rest buffaloes, respectively.

It was concluded that supplementation of high quality supplements to the buffaloes prior to the working season should be practiced in order to ensure good body condition. This will enable the buffaloes to perform work efficiently, especially early in the working season, and to maintain good body condition while working.

Another experiment was conducted by Chaidet

Table 4. Voluntary dry matter intake and liveweight changes of buffalo fed low or high plane of nutrition prior to working period.

Item	Treatment*				±SE
	LNW	LW	HNW	HW	
Dry matter intake, per day					
Rice straw					
kg	6.2[a]	6.6[a]	8.1[b]	7.8[b]	0.1
%BW	1.4[a]	1.4[a]	1.7[b]	1.7[b]	0.03
g/kg $W^{0.75}$	64.4[a]	66.3[a]	81.0[b]	79.0[b]	1.4
Total					
kg	6.2[a]	6.6[a]	10.3[b]	10.0[b]	0.1
%BW	1.4[a]	1.4[a]	2.2[b]	2.2[b]	0.04
g/kg $W^{0.75}$	64.4[a]	66.3[a]	103.5[b]	102.0[b]	1.5
Digestion coefficient, %					
Dry matter	49.4[a]	49.7[a]	57.4[b]	57.3[b]	1.1
Organic matter	54.8[a]	54.8[a]	61.8[b]	61.6[b]	0.6
Crude protein	3.8[a]	-3.7[a]	51.0[b]	50.1[b]	7.1
NDF	57.4[a]	57.8[a]	57.1[a]	57.3[a]	0.5
ADF	53.8[a]	53.2[a]	52.7[a]	52.8[a]	0.6
Liveweight changes, kg/day	-0.6[a]	-0.8[a]	1.0[b]	0.8[b]	0.2

[ab] Mean on the same row with different superscripts differ ($P<0.01$).
*LNW = low plane of nutrition prior to working period + no work.
LW = low plane of nutrition prior to working period + work.
HNW = high plane of nutrition prior to working period + no work.
HW = high plane of nutrition prior to working period + work.
NDF = neutral-detergent fibre.
ADF = acid-detergent fibre (Wachirapakorn and Wanapat 1989a).

Table 5. The effects of plane of nutrition on intake, digestibility and body condition of buffaloes prior to working period.

Item	Plane of nutrition		±SE	% increased	Significance
	Low	High			
RS intake, per day					
kg	6.4	7.9	0.1	23.4	**
%BW	1.4	1.7	0.02	21.8	**
g/kg $W^{0.75}$	65.4	79.9	1.0	22.2	**
Digestion coefficient, %					
Dry matter	49.5	57.3	1.1	15.7	**
Organic matter	54.8	61.7	0.9	12.7	**
Crude protein	0.1	50.6	5.4	>100	**
NDF	57.6	56.2	0.8	-0.7	ns
ADF	53.5	52.8	1.0	-1.4	ns
Liveweight changes, kg/day	-0.7	0.9	0.1	>100	**

ns = not significant.
** = $P<0.01$.
NDF = neutral-detergent fibre.
ADF = acid-detergent fibre (Wachirapakorn and Wanapat 1989a).

(1989) to study the effect of urea-treated rice straw and feed supplement in rice straw or urea-treated rice straw on voluntary feed intake, digestibility and working capacity in draught buffaloes. Eight castrated males, about 7 years old, with initial weight of 563.3 ± 47.8 kg were randomly allotted in a 2 × 4 factorial arrangement according to a replicated 4 × 4 Latin square design.

Two factors studied were draught which included working (W) or at-rest (NW) and feed which included four groups of feed: (1) rice straw + fresh grass (RG); (2) 5% urea-treated rice straw + fresh grass (UTRG); (3) rice straw + fresh grass + supplement (RGS); and (4) 5% urea-treated rice straw + fresh grass + supplement (UTRGS).

The experiment consisted of four periods, each lasting for 40 days. The first 20 days of each period was considered the resting period and the last 20

Table 6. Voluntary dry matter intake and liveweight changes of buffaloes offered rice straw and fresh grass (1:1, as fed basis) during working period.

Item	Treatment*				±SE
	LNW	LW	HNW	HW	
Dry matter intake, per day					
kg	6.8^{a}	7.3^{ab}	7.7^{b}	7.9^{b}	0.1
%BW	1.6a	1.7^{ab}	1.7^{ab}	1.8^{b}	0.03
g/kg $W^{0.75}$	70.9^{c}	75.3^{d}	76.0^{d}	80.5^{e}	1.3
Digestion coefficient, %					
Dry matter	52.8^{a}	54.3^{a}	51.9^{a}	54.1a	0.7
Organic matter	56.7^{a}	58.4^{a}	55.7^{a}	58.2^{a}	0.8
Crude protein	31.0^{a}	32.7^{a}	32.9^{a}	30.9^{a}	1.9
NDF	58.4^{a}	60.2^{a}	58.2^{a}	59.4^{a}	0.8
ADF	54.4^{a}	55.4^{a}	53.5^{a}	55.0^{a}	0.9
Liveweight changes, g/day	-82.2^{c}	-209.1^{d}	-36.6^{e}	-120.5^{f}	18.2

[ab] Mean on the same row with different superscripts differ ($P<0.05$).
[cdef] Mean on the same row with different superscripts differ ($P<0.01$).
* LNW = low plane of nutrition prior to working period + no work.
LW = low plane of nutrition prior to working period + work.
HNW = high plane of nutrition prior to working period + no work.
HW = high plane of nutrition prior to working period + work.
NDF = neutral-detergent fibre.
ADF = acid-detergent fibre (Wachirapakorn and Wanapat 1989a).

Table 7. Draught capability and weight change of buffaloes fed on different rations during working period (20 days).

Item	Ration				Significance	±SE
	1	2	3	4		
Area of ploughing, m^2/hour	400.9	416.1	417.9	424.7	ns	7.7
Depth of ploughing, cm	10.0	10.3	10.2	10.2	ns	0.1
Width of ploughing, cm	23.0	23.2	23.5	22.7	ns	0.3
Capacity of ploughing, m^3/hour	39.4	42.4	42.3	42.2	*	0.6
m^3/day†	157.7	169.4	169.0	168.9	*	-
Speed of ploughing, m/min	39.0	38.9	39.7	40.3	ns	-
km/hour	2.3	2.3	2.4	2.4	ns	0.04
Weight change, kg/day						
At rest period††	0.4^{a}	1.2^{b}	1.7^{b}	2.4^{c}		0.2
Working period††	-1.5^{a}	-1.2^{ab}	-0.9^{ab}	-0.8^{b}		0.2
Average	-0.5^{a}	0.0^{b}	0.4^{bc}	0.8^{c}		0.1

Ration 1 = Rice straw + fresh grass
Ration 2 = Urea-treated rice straw + fresh grass
Ration 3 = Rice straw + fresh grass + concentrate
Ration 4 = Urea-treated rice straw + fresh grass + concentrate
ns = $P>0.05$, * $P<0.05$
[abc] ($P<0.01$)
† Working 4 hours/day
†† Mean of weight changes between at rest and working period were significantly different for each ration ($P<0.01$) (Chaidet 1989).

days the working period. During each period, buffaloes received respective feeds according to treatment. The buffaloes were kept in individual pens during resting periods and allowed to plough on sandy soil during working treatment for 4 hours/day (7.00–9.00 a.m. and 2.00–4.00 p.m.). Voluntary dry matter intake (VDMI) and voluntary organic matter intake (VOMI) of UTRGS (kg/head/day, % BW/day, g/kg $W^{.75}$/day) were higher than RG, UTRG and RGS all working and at-rest ($P<.01$). Digestion coefficients of dry matter (DM), organic matter (OM), crude protein (CP), neutral-detergent fibre (NDF) and acid-detergent fibre (ADF) of buffaloes receiving urea-treated rice straw were higher than those fed rice straw ($P<0.01$), and digestion coefficients of DM, OM and CP during working were higher than at-rest periods ($P<0.01$). However, NDF and ADF digestion coefficients during working and at-rest periods were not different ($P>0.05$). Digestion coefficients of nutrients were increased by concentrate supplementation. Liveweight changes were –0.6, 0.1, 0.4 and 0.8 kg/head/day, ($P<0.01$) in respective treatment groups. However, ploughing rates were 400.9, 416.1, 417.9 and 424.7 m^2/hour respectively ($P>.05$). Speed rates were 2.3, 2.3, 2.4 and 2.4 km/hour respectively (Table 7).

Effects of Feeding Urea-Treated Straw

It has been reported that haematology of growing buffaloes was normal when fed urea-treated straw. The benefits of adding rice bran and leucaena to urea-treated straw on performance of newborn buffalo calves up to 4 months of age have been demonstrated: there were weight gains of 400, 420, 420, and 430 g/head/day ($P<0.05$) for urea-treated straw (UTS), UTS plus 500 g rice bran (RB), UTS plus leucaena (LC) (1% BW), and UTS plus RB plus LC, respectively. Urea-treated straw diets produced no difference in reproductive parameters of cows, in terms of corpus luteum disappearance, involution of uterus and first oestrus postpartum. Investigations comparing feeding untreated rice straw and urea-treated rice straw during late pregnancy and early lactation periods showed slightly higher birth weights of calves delivered from cows which received urea-treated straw. Postpartum gains of these calves were higher in groups which received urea-treated straw. Postpartum gains of these calves were greater, 80.6 kg as compared to 65.6 kg at 4 months of age, respectively (Wongsrikeao and Wanapat 1984; Wongsrikeao and Taesakul 1985).

Feeding Technology Implementation in Villages

Very few experiments have been done in villages to examine the feasibility, acceptance and perceptions by farmers of various technologies.

The research work carried out in a village by Wanapat et al. (1988) aimed at implementing potential technologies of crop residue-based feeds in order to verify their use in the farming system. The objectives of the study were to increase the buffalo draught performance by improving the nutritional status throughout the dry season. The 62, 4–5-year-old draught buffaloes were randomly allotted into five feeding groups. The groups were as follows: (1) traditionally raised; (2) morning feeding of 300 g/head/day air-dried cassava leaf (CL) for 4 months (Jan–Apr); (3) as in 2 but for 2 months (Mar–Apr); (4) morning feeding of 3 kg/head/day urea-treated rice straw (UTS), fresh, for 4 months (Jan–Apr); and (5) as in number 4 but for 2 months (Mar–Apr). The management and feeding of the buffaloes were done by the farmers who were closely assisted by researchers. Training and demonstration of feed preparations as well as management practices were conducted for farmers prior to commencing and during the course of the project. Routine daily meetings and discussions were carried out throughout the project. Monthly weight measurement, draught capability, physical appearance observations, feeding pattern, ruminal fluid sampling for ammonia-nitrogen (NH_3–N) and total volatile fatty acids (TVFAs) production were recorded. The following results are based on data collected over 1 year. The rate of body weight loss of the buffaloes could be reduced by giving CL or UTS. And providing minimal amounts of these feeds prior to morning grazing on open areas resulted in enhanced ruminal NH_3–N and TVFAs levels for intact microbes necessary for optimal in situ activities. Buffaloes fed with either CL or UTS gave similar performances. However, feeding and maintaining the buffaloes for 4 months with these morning feeds appeared to be superior to employing 2 months feeding especially when early and heavy workloads were required. Animals in the group fed additional morning feed were able to perform and exert well during the working season, particularly during earlier and initial periods of workload (Table 8, 9). Buffaloes on additional feeds were sold at the end of the year at higher prices. However, general attitudes of participating farmers were positive, showing keen interest and consistent participation. The verified technologies were easily practiced by the farmers and it was well confirmed that buffaloes with better body condition performed more efficiently and showed good body condition towards the end of working season (Fig. 1). Moreover, the farmers emphasised and convinced us that their buffaloes looked better, were better-conditioned, groomed and stronger. Because of these results they were questioned by neighbours and nearby villagers who had seen the buffaloes and were interested in purchasing them at markedly high prices. In addition the farmers also stressed that their participation had made them pay more attention to

Table 8. Draught capability of buffaloes in different feeding groups.

Group	Rectal temperature (°C) Before	Rectal temperature (°C) After	Time of ploughing (hours/day)	Area of ploughing (m^2)	Depth of ploughing (cm)	Soil moisture (%)	Soil pH
1	38.5	39.2	1.3	579.6	10.4	7.3	4.2
2	38.2	39.1	3.2	2326.9	12.4	16.3	8.7
3	38.2	38.9	2.2	2201.5	11.9	8.7	7.7
4	37.4	38.9	1.2[a]	902.0	11.4	30.8	6.8
5	38.0	39.5	2.6	1478.7	11.1	5.4	4.6

[a] In the morning only (Wanapat et al. 1988).

Table 9. Effect of feeding on pH, amnonia-nitrogen (NH_3-N) and volatile fatty acids (TVFAs) concentrations in rumen fluids of buffaloes.

Group	pH Morning	pH Evening	$\bar{x} \pm SE$	NH_3-N% mg Morning	NH_3-N% mg Evening	$\bar{x} \pm SE$	TVFAs, mmole/l Morning	TVFAs, mmole/l Evening	$\bar{x} \pm SE$
Traditional raising (1)	2.5	6.9	7.2	7.2	10.0	8.9	40.7	77.6	59.2
Supplemented DCL[a] (2+3)	7.2	7.0	7.1	8.5	13.3	10.3	68.1	85.9	77.0
Supplemented UTS[b] (4+5)	7.3	7.0	7.2	8.5	14.2	11.3	61.7	82.2	72.0
Dry season (1+2+3+4+5)	7.3	7.0	7.1+0.1	8.3	12.5	10.4+3.6	56.9	81.9	69.4+3.2
Rainy season (1+2+3+4+5)	6.9	7.4	7.2+0.1	7.2	8.9	8.0+5.3	93.8	89.7	91.8+4.3

[a] Dried cassava leaf, [b] Urea-treated rice straw (Wanapat et al. 1988).

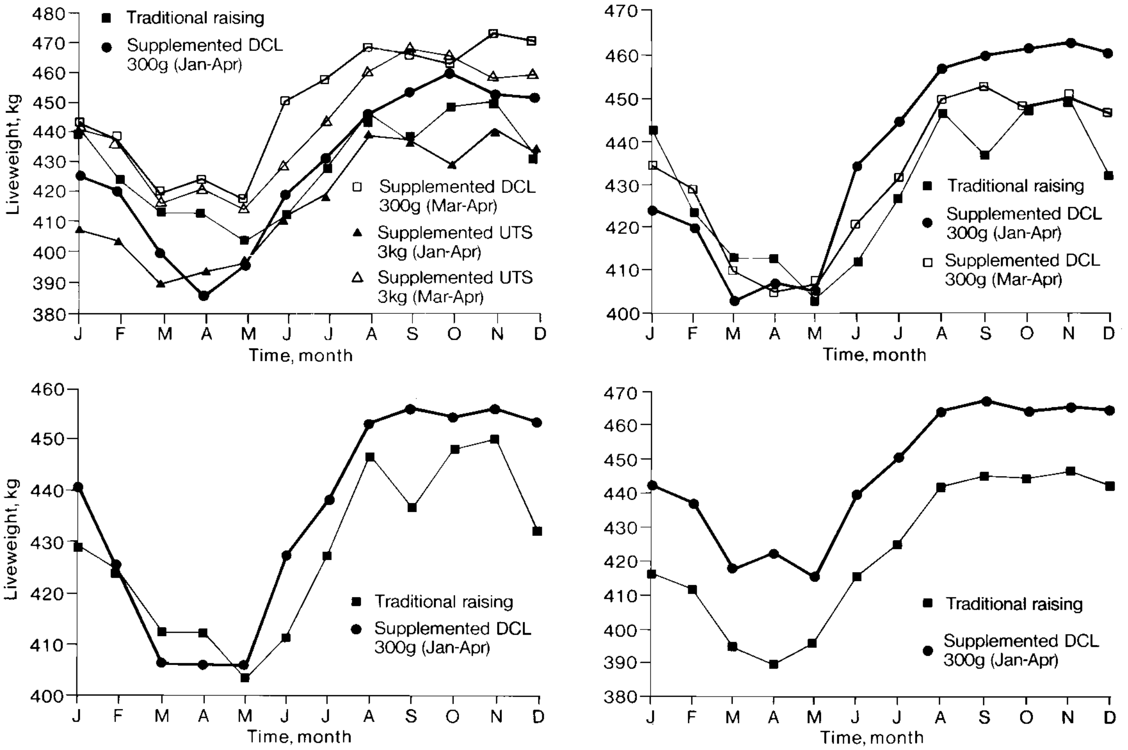

Fig. 1. Performance of draught buffaloes receiving dried cassava leaf (DCL) or urea-treated rice straw (UTS) during the dry season (Jan–Apr) and throughout the year (Wanapat et al. 1988).

the draught buffaloes, and to realise the benefits of using available on-hand crop residues.

Proposed Feeding Pattern

It is common in many areas of developing countries that crop production is the most prevalent occupation. It is therefore imperative to organise animal feeding patterns to best suit the production system. In the working regime of rainfed village farmers, the high peaks of workload were at the end of dry season and throughout the growing season (Fig. 2) (Wanapat et al. 1988). Therefore, it is highly desirable to supplement low-quality roughages with minimal amounts of treated (urea) crop residues such as rice straw during the dry season, to ensure better rumen ecology and better condition of the animal.

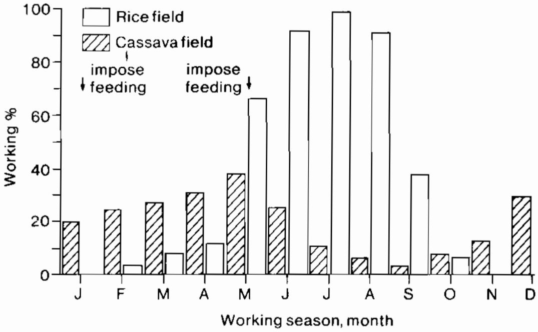

Fig. 2. Distribution of work throughout the year in a rainfed village (Wanapat et al. 1988).

Conclusions

Feeding practices commonly used by smallholder farmers are simple and depend on naturally available feed resources, particularly crop by-products in the various seasons. Therefore, performance of livestock in terms of liveweight, reproduction, and working capability are influenced by seasonal feeds and level of feeding. In light of the present knowledge of buffalo nutrition and feeding, more research needs to be done on the limitations imposed by potential acceptance of improved technologies by the farmers. A better understanding of what is happening to the feedstuffs when ingested by the buffaloes and buffalo feed requirements is necessary. Investigations of feeding systems for periods of feed scarcity and during the working regime are needed to reduce the detrimental influence on reproductive performance, milk production, calf mortality, calving interval and the draught capability of buffaloes. It is also suggested that feeding strategies of draught buffaloes/cattle in Southeast Asia be based on seasonally available crop residues, in order to maintain body condition during the dry season so that the animal is ready for the early working season and a long growing season.

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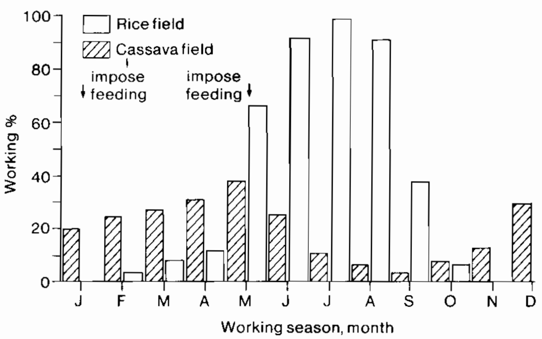

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Measurement of Energy Expenditure in Working Animals: Methods for Different Conditions

P.R. Lawrence and R. Anne Pearson*

Abstract

The following terms are defined and briefly discussed in relation to draught animals: a) heat output, b) energy expenditure, c) direct measurement of heat output, and d) indirect measurement of energy expenditure. Direct measurement of heat output appears not to be a feasible option for draught animals. Most indirect methods rely on measuring gaseous exchange. The relationship between gaseous exchange and energy expenditure is discussed. The classic open circuit apparatus can be used for 'laboratory' studies when animals are resting in a respiration chamber or at work on a treadmill or circular race. All available methods for measuring gaseous exhange of animals working in the field involve an airtight face mask and sampling of expired air. In these systems, either a sample which is a constant proportion of the total flow is collected for subsequent analysis or a representative sample of each breath is collected and simultaneously analysed. The sums of gas concentration terms times the corresponding volume of each breath are electronically logged to give total gaseous exchange. Both approaches rely on flowmeters which have a fast and accurate response. The advantages and disadvantages of all these approaches are discussed.

The theory and applicability of two tracer methods are discussed. Labelled carbon methods appear not to be very accurate but may be useful for determinations over a few hours. The double-labelled water method may find application for measurements over 1 or 2 weeks now that several of the objections to its use on large ruminants appear to have been met. However, both types of tracer measure only CO_2 output from which energy consumption has to be inferred, and the latter method is expensive. Two 'derivative' methods for estimating energy expenditure involve counting the number of heartbeats and measuring the type and amount of physical activity which the animal indulges in. Both methods rely totally on the application of data from laboratory studies to link these parameters to energy expenditure. The validity of these methods as well as the techniques used for collecting the relevant data from animals in the field are briefly discussed.

The paper ends with two possible alternative methods (one direct and one indirect) from human physiology which might be worth developing.

Introduction

DRAUGHT animals provide most of the power on farms in developing countries and there seems little reason to suppose that the situation will change much in the foreseeable future (Smith 1981). At the same time, more land is being brought under cultivation to meet the increasing world demand for agricultural produce, leaving less land on which such animals can be grazed. It is therefore essential that, wherever possible, the use of draught animals be rationalised so that the maximum amount of work may be obtained from the limited amount of food available.

Since draught animals expend conspicuously more energy than other kinds of livestock it is

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central to this aim to be able to measure the amount of energy used by draught animals during work so that food requirements may be predicted.

With the current renewal of interest in the study and use of draught animals it is felt that a review of the methods and potential methods available for measuring energy consumption of animals working under field conditions may be useful for scientists working in this field.

Direct Measurement of Heat Output

The many and intricate methods for the direct measurement of heat output by animals have been recently reviewed (McLean and Tobin, 1987, chap. 5). All reported methods for large animals involve keeping the animal enclosed in a chamber for extended periods (e.g. Pullar et al. 1967) and on this account alone render them unsuitable for draught animals.

Even if it were technically feasible to measure the heat given off from the body of a working animal several theoretical and practical problems would still remain:

1) Air which comes into contact with the animal either by being breathed or simply by passing over the skin usually undergoes changes in temperature and humidity. The resulting enthalpy changes in the air can be quite large and are accounted for in the case of animals in chambers by carefully and continuously monitoring a constant proportion of the air entering and leaving the chamber. In a free-ranging animal such a procedure would be virtually impossible.

2) Heat production by an animal often causes a rise in body temperature in the short term rather than being given off by radiation or convection. A 1C° rise in body temperature is roughly equivalent to the heat output during 1 hour at rest. Direct measurements of heat output by themselves would thus be of little value for animals whose work levels are continually changing. Also under these conditions, correction factors derived from simple measurement of deep body temperature would not be appropriate because the body of a working animal warms and cools in an uneven manner. Weighted averages of mean skin and deep body temperature can be used to give a better idea of average body temperature (McLean et al. 1983) but even this still leaves a large margin of error.

3) Draught animals often expend energy to do work on their environment which is not directly measurable as heat, and even if the work is ultimately degraded to heat (e.g. the heat produced by friction as a plough is drawn through the soil), it may not be released in circumstances under which it can be measured.

Indirect Measurement of Heat Output

As the word implies, indirect methods involve measuring something from which heat output may be calculated or inferred.

The indirect methods which are most widely used and which have the firmest theoretical base depend on the connection between the heat produced by the consumption of metabolic fuel by an animal and its gaseous exchange. Most other indirect methods use other measurable parameters to make inferences regarding gaseous exchange measurements to calibrate them and could thus be called secondary indirect methods.

Connection Between Heat Production and Gaseous Exchange

The fact that a quantitative connection exists between these two factors and that therefore one may be used to measure the other has formed a central theme in animal science for over two centuries (Seguin and Lavoisier 1789). The present day derivation of a formula connecting gaseous exchange and heat production depends on the following assumptions:

a) That heat is produced only by the oxidation of carbohydrates, fats and proteins to carbon dioxide, water and urea;

b) That dietary fats, carbohydrates and proteins have consistent elemental compositions;

c) That no heat is produced without gaseous exchange. In practice this means carrying out gaseous exchange measurements at submaximal levels of energy expenditure and over a long enough period for anaerobic respiration to be quantitatively unimportant;

d) That no gaseous exchange occurs without heat production (e.g. that the animal is not washing out abnormal quantities of CO_2 from its blood stream by hyperventilation);

e) That metabolic processes other than oxidation of nutrients are quantitatively unimportant. Blaxter (1962), however, has pointed out that the most common of these in ruminants, i.e. the production of fat from carbohydrate, causes little upset.

These assumptions are generally quite reasonable when applied to mature draught animals that are neither gaining nor losing large amounts of weight.

Table 1. Data used for the determination of heat production in the body (after Brouwer 1965).

Substance	O_2 consumed (Std l)	CO_2 produced (Std l)	Heat produced kJ
Fat (values/g oxidised to CO_2 + water)	2.013	1.431	39.8
Carbohydrate (values/g oxidised to CO_2 + water)	0.829	0.829	17.6
Protein (values/g of urinary nitrogen on oxidation to CO_2 + water + urea)	5.98	4.84	114.8
Methane (values/std l oxidised to CO_2 + water)	2.00	1.00	39.4

A formula for predicting heat output can be derived using the data drawn up by Brouwer (1965) (Table 1), which gives the average gaseous exchange and heat output associated with the oxidation of the three major classes of nutrient molecule to CO_2, water and, in the case of protein, urea.

Consider first of all an animal oxidising x grams of carbohydrate and y grams of fat then:—

Total oxygen consumption $C = 0.829\,x + 2.0123\,y$

Total CO_2 production $P = 0.829\,x + 1.431\,y$

Total heat production $H = 17.6\,x + 39.8\,y$

Elimination of x and y gives

$$H = 16.16\,C + 5.09\,P \qquad (1)$$

If the animal also oxidises protein, then according to this formula and Table 1 it should produce 121.3 kJ/g of urinary nitrogen. In fact it produces only 114.8 kJ.

In ruminant animals which produce substantial amounts of methane there is a further source of error. The production of 1 l of methane represents 39.4 kJ of energy which the animal cannot use. This loss calculated using equation (1) is 37.4 kJ.

Incorporating these discrepancies between actual and calculated values in equation (1) we get:

$$H = 16.16\,C + 5.09\,P - 6.5\,U - 2.0\,M$$

where U = grams of urinary nitrogen
and M = litres of methane.

In practice for ruminants on high carbohydrate, low protein diets, the last two factors account for less than 1% of the total (Table 2) and can thus be ignored in most draught animal work.

A further simplification which can often justifiably be made is to relate heat production to oxygen consumption alone. The ratio

$$\frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$$ also known as the

respiratory quotient or RQ can theoretically vary from 0.7 when an animal is oxidising nothing but fat to 1.3 when it is producing fat at a maximum rate from carbohydrate. However, even at these extremes, using oxygen alone will produce errors only of the order of ±9% since the oxygen factor in equation (1) accounts for about 77% of the total calculated heat output. Reasonably well-fed draught animals will usually have RQs in the range 0.8–1.0 so assuming an average of 0.9 will enable heat production (kJ) to be calculated as oxygen consumption (l) × 20.7 with an uncertainty of ±2.4%. One word of caution that does need

Table 2. Calculation of 24 hour energy consumption of a 725-kg ox fed at maintenance.

Oxygen consumption	3053 l
CO_2 production	3002 l
Methane production	213 l
Urinary nitrogen (estimate)	50 g

Energy consumption

= (3053 × 16.16) + (3002 × 5.09) − (50 × 6.5) − (213 × 2.0) kJ
= 49336 + 15280 − 325 − 426 = 63865 kJ

Relative importance of the various factors

O_2	77.3%
CO_2	23.9%
Urinary N	0.5%
Methane	0.7%

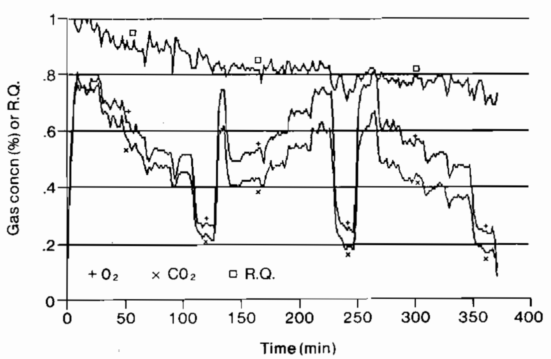

Fig. 1. Oxygen consumption and CO_2 production (as a percentage of total airflow) and RQ of a 765-kg ox during a working day.

mentioning in connection with draught animals is that during the course of a working day this whole range of RQ values can be exhibited (Fig. 1) as the animal uses up the carbohydrate from its morning meal and has to rely more and more on its fat reserves for energy. Measurement of oxygen consumption alone will therefore give results which are too high at the start of work and too low at the end.

When attempts are made to calculate energy expenditure from CO_2 production alone the RQ assumes a much greater importance because the CO_2 factor in equation (1) is only 24% of the total. An uncertainty of 0.1 in the value of the RQ will produce an error of 10% in the calculated energy expenditure.

Methods for Measuring Gaseous Exchange in Animals

Classic 'Open Circuit' System

This relies on air being provided for the animal at a constant rate. The change in gas concentrations in the airflow is monitored and the gaseous exchange for any particular gas during any period is calculated as the product of the flowrate, the time and the average concentration difference.

An example of this kind of apparatus which can be used for large draught animals is the one at the CTVM in Edinburgh (Fig. 2). In this apparatus the constant airflow is provided by a multistage centrifugal pump driven by an induction motor. The air is drawn through a face mask worn by the animal when it is working or through a respiration chamber when it is resting. The flowrate for a particular experiment is chosen so that the CO_2 concentration in the air distal to the animal does not exceed 1%. This ensures that the CO_2 if rebreathed will not stimulate the animal's respiration (Mountcastle 1974). A sample of the mixed expired air is dried out and passed through one channel of a differential paramagnetic oxygen analyser (fresh air goes through the other) and through infrared CO_2 and methane analysers. The outputs from all these meters are amplified and fed into a modified personal computer where they are sampled at 5Hz. Values are averaged at suitable intervals and stored for subsequent calculations of gaseous exchange.

The advantages of such systems are that they are reliable and accurate and can be used for measurements over any length of time from a few minutes to 24 hours. The main disadvantage is that the apparatus is not portable, so for working animals, some arrangement such as a treadmill or circular race must be made to enable the animal to work whilst staying more or less in one place. This

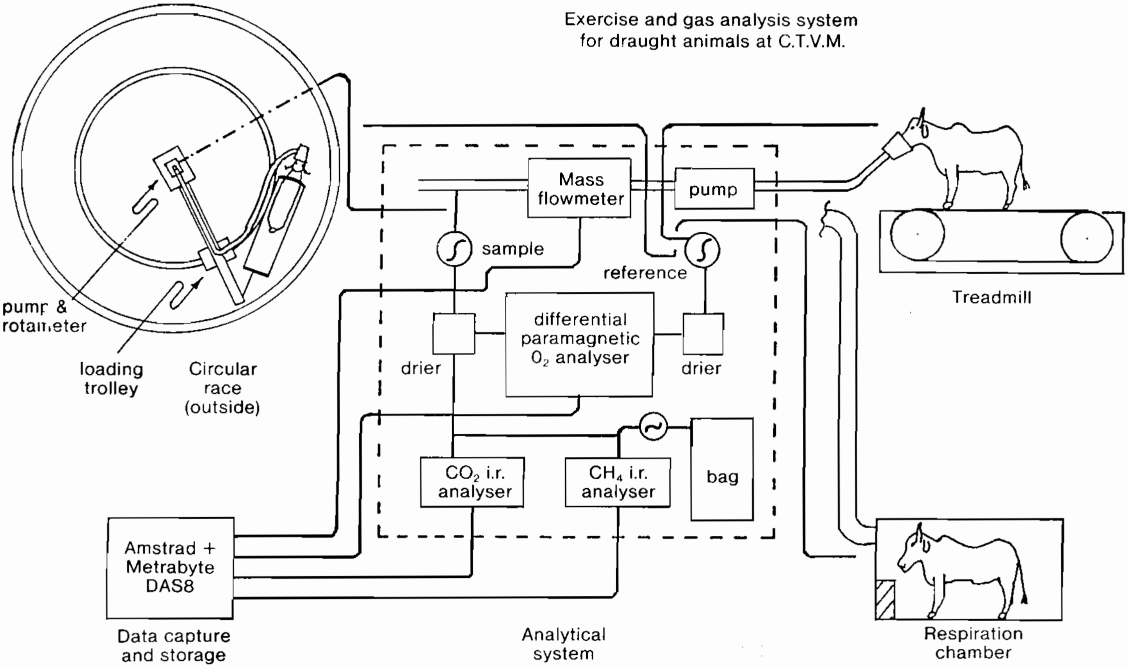

Fig. 2. Open circuit gas analysis system for use with large draught animals at work and at rest.

also precludes the animal doing any 'normal' agricultural work such as ploughing, and although various aspects of the 'natural' environment such as muddy conditions and walking up and down hill may be simulated using the circular race and treadmill respectively, the technique must remain essentially a 'laboratory' one.

Portable 'Breath-by-Breath' Analysers

An alternative to the classic open circuit system which mixes expired air with air pumped through the system is one in which the experimental animal wears an airtight face mask fitted with a flowmeter which measures the volume of each breath (Fig. 3). In some instruments a sample of the expired air is taken which is a constant proportion of this volume. The cumulative sample therefore has a gas concentration which is the average of all the air expired in a given time. Subsequent analysis of this sample in the laboratory followed by application of correction factors for temperature, atmospheric pressure and humidity followed by multiplication of concentration terms by total volume of expired air gives the total gaseous exchange. According to McLean and Tobin (1987) the first apparatus built on this principle was made by Zuntz et al. in 1906 but it has only recently been applied at the University of Hohenheim in Germany to oxen (Clar 1988, pers. comm.). Such systems have the advantage that providing suitable analysers are available, oxygen, carbon dioxide and methane can all be determined. The main disadvantages are: (a) changes in metabolic rate during an experiment cannot be followed unless a lot of samples are taken for analysis, and (b) the apparatus can never be used very far away from the laboratory because it is difficult to preserve gas samples for more than about 24 hours without their changing in composition.

An alternative to collecting samples is to analyse each breath on the spot. In practice this restricts the analysis to one component with oxygen being the preferred one. Hornicke et al. (1974) adopted this method for use with horses. Airflow was detected using a strain gauge pneumotachograph and oxygen concentrations monitored by a fast polaragraphic oxygen electrode. Signals from both instruments were transmitted by radio back to a computer for analysis. Although unlike some other flowmeters, this type of flowmeter causes virtually no obstruction to the passage of air. It has a tendency to become contaminated by dust and moisture and

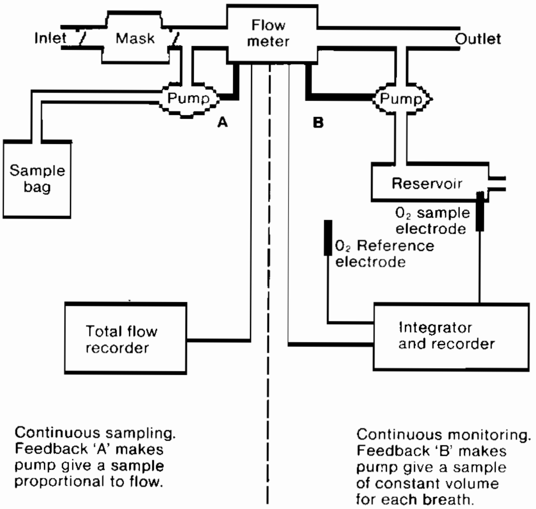

Fig. 3. Basic layout of portable 'breath-by-breath' analysers.

its output to become nonlinear with respect to flow. Also, the rate of response of the oxygen sensor is not really rapid enough to follow exactly the changes from one breath to another (90% response in 300 msec).

Schroeter at Imperial College, London, working in conjunction with AFRC Engineering, Bedfordshire, England (pers. comm.) has made a system which uses a heated pneumotachograph to avoid problems with condensation of water vapour. Oxygen analysis is performed by polaragraphic oxygen electrodes which occupy a 'reservoir' through which samples from individual breaths are pumped. At any one time the reservoir contains gas from several previous breaths so that the gas concentrations in the reservoir change at a rate that is slow enough to be followed accurately by the sensors. Signal processing and calculation of oxygen consumption is done by a microcomputer which forms part of the portable apparatus.

Another apparatus which may prove useful for draught animals is the 'Oxylog.' The apparatus was originally designed by Humphrey and Wolff (1977) for use with human beings. It is commercially available from P.K. Morgan Ltd., Kent, England, and has proved reliable in long-term field trials, and accurate when compared with laboratory methods (Harrison et al. 1982). It has a turbine flowmeter mounted on the inlet side of the face mask to avoid condensation problems and also has a sample reservoir to provide a 'running average' oxygen concentration for its polaragraphic electrodes to measure. Its electronic system calculates total oxygen consumption and total volume of inspired air at STP after making corrections for atmospheric temperature, pressure and humidity.

It can be calibrated in the field by displacing a known volume of air through the flowmeter using a reciprocating displacement pump whilst surrounding the oxygen electrodes with a standard gas of known composition. Adaptations to enable this apparatus to be used on working draught animals are at present under way at the CTVM in Scotland and involve the production of a larger flowmeter and a suitable valved face mask.

Two problems common to all breath-by-breath analysers are making an airtight seal between the mask and the animal's face and ensuring that the valves cause minimal restriction to the passage of breath. A further potential problem involves animals that pant to keep cool such as cattle and buffalo. The CO_2 concentration in the breath of a panting sheep attached to an open circuit system with a constant air flow is shown in Fig. 4. The sample was taken from a point within 100 mm of the sheep's mouth and was pumped directly to the CO_2 meter so that the peaks on the graph follow the CO_2 concentration in individual breaths. It can be seen that substantial changes in CO_2 concentration occur only occasionally and that the majority of breaths involve very little gaseous exchange. This implies that panting animals have high ventilation rates but the expired air has a much lower CO_2 increment, and presumably oxygen decrement, than usual. This would greatly lessen the accuracy of total oxygen consumption measurements on a breath-by-breath basis.

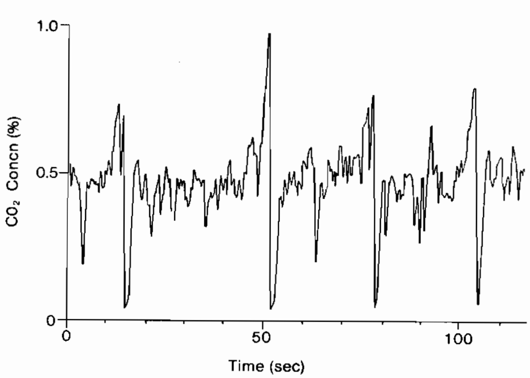

Fig. 4. Carbon dioxide concentration in an open circuit system. The experimental animal was a sheep which wore a face mask whilst walking at 1.5 m/sec on a flat treadmill. The sheep was panting and the sample point was 100 mm from its mouth.

Secondary Indirect Methods

Tracer Methods

Carbon Dioxide Entry Rate

A substance such as CO_2 which is continuously produced and excreted forms a metabolic pool in the body. If labelled CO_2 is continuously infused into this pool at a constant rate it will eventually reach an equilibrium concentration in the excreted CO_2 which depends on the rates of infusion of the label and the rate of excretion of endogenous CO_2. Under these conditions the amount of label entering the pool equals the amount excreted in any given time. Thus if x units of label are infused in 1 hour and the concentration of label in the excreted CO_2 is y units/l then the volume of CO_2 excreted is $\frac{x}{y}$ l or, expressed in terms of rates and concentrations,

$$a = \frac{b}{c}$$

where a = rate of CO_2 excretion
b = rate of infusion of label
and c = concentration of label in the excreted CO_2.

This approach was applied to cattle by Young (1970) and by Corbett et al. (1971) in sheep. Labelled CO_2 was infused as $NaH^{14}CO_3$ and the concentration of label determined in expired CO_2 or in CO_2 extracted from blood, urine or saliva. In general, comparisons between energy expenditure determined by CO_2 entry rate and by direct measurement of gaseous exchange agreed to within 15–20%.

The main intrinsic source of error in the method is that the CO_2 pool of the body is not homogeneous and physiologically consists of several interlinked pools in which the CO_2 turnover rates are quite different. Also there exist several CO_2 'fixing' reactions which can remove CO_2 from the pool altogether. The errors caused by the inhomogeneity of the CO_2 pool can be minimised by maximising the length of time during which CO_2 label is infused before sampling starts (Whitelaw (1974) recommends 12 hours), and the length of time during which samples are taken (24 hours). It is also important that the metabolic rate of the subject be relatively constant during the sampling period, because the turnover rate of the CO_2 pool (once every 1–2 hours) is slow compared with the rate at which metabolic rate can change.

This last factor is one of the major objections to the application of this method to working animals, although the method applied to resting animals has been refined to the extent that Whitelaw et al. (1972)

were able to measure the CO_2 output of sheep to within 2–4% of the values obtained from gaseous exchange measurements. The other major inconvenience of the method is the necessity of continuous and precise infusion of the labelled bicarbonate solution. White and Leng (1969) devised a method which involved administering a single dose of labelled bicarbonate but it suffered from the disadvantages that body fluid had to be sampled much more frequently than in the continuous infusion method and mathematical analysis of the results was complex because of the different rates of turnover of the components of the CO_2 pool.

Double-Labelled Water

Hydrogen is lost from the body mainly as water, whereas oxygen is lost both in water and as part of the CO_2 molecule. The oxygen atoms in body water and those in CO_2 are kept in equilibrium due mainly to the action of the enzyme carbonic anhydrase. Therefore, if an animal drinks a dose of water in which both the hydrogen and the oxygen are labelled, the specific activity of the oxygen in the body water will decrease at a faster rate than that of the hydrogen. The difference in the two rates of decrease times the volume of the total body water (which may be estimated from the initial, equilibrium specific activity) will give the rate of loss of CO_2.

The theoretical basis of this method was worked out by Lifson et al. (1955) and has been applied to a variety of animals from mice (Lifson and McClintock 1966) to people (Schoeller and van Santen 1982).

In practice the method involves giving a dose of water enriched with ${}^2H_2{}^{18}O_1$ and determining the specific activity both of ${}^2H$ (deuterium) and ${}^{18}O$ in any body fluid such as saliva or urine. Measurements are taken first of all between 0 hour and 6 hours to determine both the initial equilibrium specific activity and the total body water and again, in the case of human beings, after 10–14 days, by which time the difference in the initial and final ratios of the specific activities of the two isotopes is large enough to be accurately measured. The rate of loss of CO_2 may then be determined as described above and multiplied by the elapsed time to give the total amount of CO_2 produced.

The main advantage of this method is that it causes the minimum of inconvenience since it does not involve the attachment of any apparatus to the experimental subject, and samples are required at infrequent intervals. Also neither of the isotopic labels is radioactive.

The disadvantages are that the accurate determination of the isotopes requires sophisticated analytical techniques involving mass spectrometry and that the method only gives a measure of total CO_2 production.

The double-labelled water method may find application to ruminant draught animals because of the ease with which it can be applied in the field. However, the length of time necessary for one determination (5–14 days) might prove inconveniently long. For example, the method would not lend itself to being used in any experiment requiring determinations of energy expenditure during only one working day. Also, the rumen contains a large reservoir of water not found in other types of mammals. This may invalidate the method firstly by preventing the rapid and complete equilibrium of oxygen atoms between CO_2 and water, and secondly because the total mass of body water may change by an unacceptably large amount during the course of an experiment.

A further possible drawback to applying the method to ruminants is that, as originally formulated, it depends on the assumption that hydrogen is lost from the body only in water. In ruminants this assumption is not true as hydrogen is also lost as part of the methane, which is produced by microbial fermentation in the rumen and also, on occasions, even as molecular hydrogen. The corrections necessary to allow for this loss would depend on such factors as the amount of methane produced (which can be as much as 200 l/day for a 400-kg ox, but is not directly measurable in the field) and the extent to which the hydrogen in the methane molecule is derived from or equilibrates with the hydrogen in body water.

Recent work with sheep at the Rowett Institute in Scotland (Midwood et al. 1989) has shown that the volume of water in the rumen is not a critical factor and that it is possible to make allowances for changes in total body water. Loss of methane causes an underestimation of energy consumption but only by some 3%. However, this also may be compensated for since the methane production associated with any particular diet can be estimated from the composition of the feed.

Even with all the technical problems removed the main practical one at present is the cost of the labelled water. Although, for human beings, this has dropped from an estimated US$3000/dose in 1965 (Lifson and McClintock 1965) to US$225 in 1982

(Schoeller and van Santen 1982), the cost of dosing draught animals at, say, US$1000 a time in sufficient numbers to obtain statistically reliable data remains prohibitive.

Measurement of Energy from Heart Rate

Richards and Lawrence (1984) have shown that an empirical relationship exists connecting heart rate and rate of energy consumption in working cattle and buffalo such that

$$E = 24.94\,R - 16.25 \qquad (2)$$

where E = rate of energy consumption per unit metabolic body weight (W/kg$^{0.75}$) and R = relative heart rate defined as

$$\frac{\text{heart rate of animal when working}}{\text{heart rate of animal when standing still}}$$

As it stands, equation (2) may be used to measure the rate of total energy expenditure at any particular time. In order to measure energy expenditure over an extended period, the equation can be modified as follows.

If the heart rate when the animal is standing still is 'b' beats/min then an observed increase of 'b' beats/min would be caused by an increase in the rate of energy consumption of 24.94 W/kg$^{0.75}$.

$$\text{Thus 1 beat/sec} \equiv \frac{24.94 \times 60\ \text{W/kg}^{0.75}}{b}$$

Bearing in mind that 1 W = 1 J/sec, this means

$$\text{1 beat} \equiv \frac{24.94 \times 60\ \text{J/kg}^{0.75}}{b}$$

$$\text{or 1 beat} \equiv \frac{24.94 \times 60 \times M^{0.75}}{b}\ \text{J}$$

for an animal of liveweight M kg.

Thus if 'n' heartbeats are recorded from a working animal in a time 't' min, the total extra energy used to do the work is:

$$\frac{24.94 \times 60 \times M^{0.75}\,(n - bt)}{b}\ \text{J.}$$

There are several problems in applying this formula to animals working in the field. Firstly, the basal heart rate may change during the work period. Secondly, precise measurements of all the heartbeats over an extended time are technically difficult. Electrical interference from muscle action potentials, the accumulation of sweat on the animal's skin and mechanical dislodging of electrodes often make identification of individual heartbeats by automatic electronic instruments difficult. Even if these last two problems could be overcome, the confidence limits of equation 2 calculated from the original data of Richards and Lawrence (Fig. 5) are such that energy consumption can never be estimated very accurately from relative

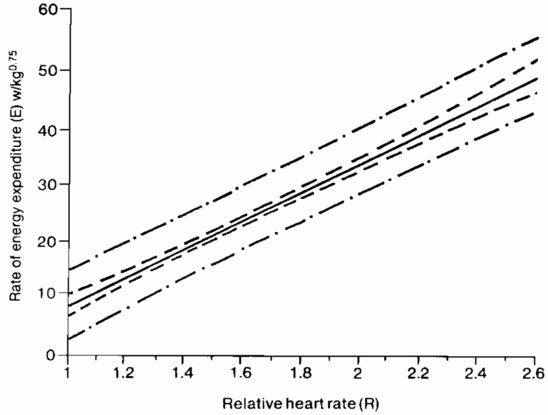

Fig. 5. Confidence limits connected with the prediction of rate of energy consumption from relative heart rate in oxen and buffalo. Original data from Richards and Lawrence (1984).

E = 24.94 R = 16.25

where E = rate of energy consumption per unit metabolic bodyweight (W/kg$^{0.75}$).

R = relative heart rate

$$= \frac{\text{heart rate of animal when working}}{\text{heart rate of animal when standing still}}$$

———— 95% confidence limit of the mean

—·—·—·— 95% confidence limit of a prediction of E from one measure of R from an individual animal

heart rate. A measurement of relative heart rate of 2.5 would give an estimate of energy expenditure accurate to within ±13% 19 times out of 20. This accuracy would drop to ±69% as the relative heart rate dropped to 1.0. However, the formula derived by these authors is a general one and it is often possible to obtain better correlations between relative heart rate and energy expenditure for individual animals. In this case, more precise estimates of energy expenditure in the field could be obtained from relative heart rate providing facilities were available to 'calibrate' the animals concerned. Even so, animals may not show the same relationships between energy expenditure and heart rate in the field as they do in the laboratory (Brockway and Whitelaw 1970).

A Factorial Method

A final method, and at present the only technically feasible one for long measurements, is a factorial method based on the extra energy used by draught animals to perform the basic types of movements involved in their work. This scheme is an extension of the one put forward by the Agricultural Research Council (1980) and has the following factors:

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

Applications of this formula to the energy expenditure of working oxen have been described by Lawrence (1985, 1986).

The main and obvious objection to the use of this formula is that the factors A–D are derived from 'laboratory' experiments in which the animals work under conditions which are often very different from those found in the field. However, it has the advantage of being easily applicable to fairly large numbers of animals, and the quantities which have to be measured such as distance travelled and work output are often of interest for their own sake.

Two Possible Methods for Future Use

Both methods were developed and have been used successfully on human subjects. One method is direct, the other indirect.

a) *The direct method* is a calorimetry suit (Webb et al. 1972) which consists of a garment covering the body and made of fine plastic tubing through which water is slowly pumped. The whole is covered with a thick insulating outer garment. The rate at which the water is pumped round the various parts of the inner garment is controlled by a series of valves and feedback mechanisms so that the subject is neither hot enough to sweat nor liable to hypothermia. The temperature rise of the circulating water times its flow rate gives the rate of production of heat at the skin surface. Evaporative heat loss is estimated by carefully weighing the subject to determine water loss. If this method were applied to draught animals this latter factor would have to be determined some other way (e.g. by the animal breathing in and out through a heat exchanger). In some respects the method would be easier to apply to a draught animal than a human, namely the shape of the suit would be simpler and the necessary ancillary equipment could be drawn along in a small cart.

b) *The indirect method* developed by the same team (Webb and Troutman 1970) is called the metabolic rate monitor and is a portable open circuit device, in which air is drawn through a face mask by a pump whose speed is controlled by a feedback loop activated by two polaragraphic oxygen sensors, one of which is in the airstream entering the mask and the other in the airstream leaving it. The loop adjusts the speed of the pump so that the difference in oxygen concentration is maintained at some fixed value, usually 1%. The speed of the pump motor is proportional to the applied voltage as is the rate at which the air is pumped through the mask. Integration of the applied voltage with respect to time gives the flow in any period which is then simply multiplied by the oxygen difference (i.e. 1%) to give total oxygen consumption.

Application of this principle to draught animals would give a totally portable instrument, mechanically simple which would not depend on an airtight face mask. Maximum airflow rates would have to be rather high (of the order of 1500 l/min) as would the battery power requirements, but for animals used to pulling and carrying loads this would present no problem.

Conclusions

There are many methods for determining energy consumption of large animals available, with varying degrees of accuracy and reliability, though surprisingly few have actually been applied to working draught animals.

All the methods mentioned have inherent problems. Of the gaseous exchange methods the classic open circuit devices are expensive and complicated to set up and the animals are restricted to the laboratory. The portable gas analysers show great potential promise but are largely untried with draught animals. They are also complex and expensive and often difficult to calibrate and repair, they cannot be used for 24-hour measurements and may be inaccurate if the animal pants.

Of the two tracer methods, the CO_2 entry rate requires continuous infusion of label into the animal, and the double-labelled water method, although potentially ideal for measurements over 1 or 2 weeks with the minimum disturbance to the animal, is as yet untried with draught animals, and likely to prove prohibitively expensive. Both tracer methods are inherently inaccurate methods of measuring heat output because they measure CO_2 production and not oxygen consumption.

Measurement of heart rate over any length of time is technically difficult and the results correlate poorly with energy expenditure even under laboratory conditions.

The factorial method also relies exclusively on factors derived from laboratory studies which may not be applicable in the field.

No direct method for the determination of heat production has ever been applied to working animals but it may be possible one day to design a suitable calorimetric suit.

In this paper we have resisted the temptation to pick out any 'favourite' methods for determining energy expenditure. The choice of method is very wide and those which may seem unpromising today may very well be the methods of choice tomorrow because of some unforeseen technical advance. Our advice to anyone looking for a method for a particular project would be:

a) To decide which method is the most suitable bearing in mind the required degree of accuracy and the number of animals you want to test in a given time;
b) To look carefully at your budget, particularly capital and running costs;
c) Perhaps most important of all, to ensure that you have the technical and human resources necessary to run and maintain the system you have in mind.

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Performance Limiting Factors in Draught Animals: Can They be Manipulated to Improve Output?

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Abstract

Farm draught animals are usually at their peak of adaptability and working capacity. In winter or at low ambient temperatures animals should be worked well below their normal capacity. These lower limits of work capacity are also reached at high ambient temperatures, or in the case of heavy load pulling and fast running. Since these activities are normally carried out with great efficiency, it is obvious that a high working performance is possible with slight alteration in work pattern. Animals, equipment, soil and environment contribute to the work output, and improvements either by proper selection techniques of animal and equipment or through modifications of soil or environment or both are possible.

Animal System

WORK performance largely depends upon animal structure and coordination in various physiological capacities related to work. Heavy animals possess more pulling capacity than light animals (Goe and McDowell 1980; Goe 1983). The body dimensions and morphology of large animals differ from small animals. Large animals, though they are able to pull more, are not as manoeuvrable as smaller animals and hence move slowly (Upadhyay 1989). Thus large animals (elephant, buffalo, crossbred) are best suited for heavy work like load pulling, and smaller animals (horse and zebu cattle) are best suited for speed (tillage or carting). Genetic factors within a species play a major role in performance capacity. This is particularly true for cattle and buffalo, which have a higher capacity to work, but work output is limited. Obviously the environment and genetic interaction limit performance. Definite improvements in performance of selected animals may be achieved by proper training, feeding and management (Howard 1980; Goe 1983; Upadhyay 1984; Pearson and Lawrence 1989).

During work the animal has to adjust to local conditions and to work. In hot climates the adaptation is twofold: first to work, second to climate. The adjustment to the limiting factors is related to the physiology of the animal, i.e. oxygen supply to working muscle, increased heat of work and environmental heat; all involve definite systems within the body for optimum oxygen utilisation, transport and thermoregulation.

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Physiological Limiting Factors

Increased metabolic activity as a response to work is economical at environmental temperatures which do not stress physiological systems, and do not require additional mechanisms for heat dissipation. Both extreme cold and heat uneconomically utilise available energy for heat production and dissipation, respectively, instead of work. A significant difference exists in the mechanism for maintaining normal activity. The explanation for this is the difference in the energy requirements of muscle at high levels of activity. Work during low temperature conditions does not increase metabolic activity or body heat content to the same levels as in hot or hot/humid periods; under such conditions heat of work is used to maintain body temperature instead of causing stress.

Work leads to adjustments in the various organ systems involved in the work process. Work increases muscle metabolism several-fold above the resting level and therefore adjustments are made in the uptake and transport of oxygen by the blood and its utilisation in muscle tissues. Sustained muscular activity over prolonged periods depends mainly on the aerobic process, and oxygen supply may be a limiting factor. During prolonged work the requirement for oxygen by muscle increases and the significant changes which occur with prolonged work period that seem important in draught animals, as in marathon runners and horses, are: increased pulmonary ventilation (Upadhyay and Madan 1985), increased cardiac output (CO) through increased heart rate and stroke volume (Nangia et al. 1980; Upadhyay and Madan 1986), increased peripheral circulation, and increased blood and plasma volume (Upadhyay and Madan 1988). Increased muscle activity produces greater heat of work, which needs to be eliminated by various thermoregulatory processes to sustain work by maintaining body temperature (Moran 1973; Nangia et al. 1980; Mathers et al. 1984; Upadhyay 1987; Pietersen and Ffoulkes 1988). Besides the above factors sustained muscular activity is also limited by inadequate diffusion of oxygen from the lung alveoli into the blood (Astrand and Rodhal 1977), and from the blood into muscle and by the capacity of muscle to use oxygen (Engelhardt 1977; Upadhyay and Madan 1985).

Cardiorespiratory Functions

In the transition from rest to exercise the cardiovascular system undergoes remarkable changes in mammals (Engelhardt 1977; Rowell 1974; Nadel 1980; Bell et al. 1983; Upadhyay and Madan 1986; Upadhyay 1988). During the initial stages of rhythmic muscular activity the CO increases as a result of greater sympathetic drive and then more gradually until a steady state is achieved according to the necessity of blood flow and intensity of work. In light and moderate work on a treadmill it may take 1–2 min to adapt, but heavy work may require longer periods. Cardiac activity increases due both to intensity of work and to speed of the animal at work (Parks and Manohar 1983). Animals running at fast speeds attain greater rise in CO than ruminants in whom capacity to run is limited. Two CO determinant factors, stroke volume and heart rate, adjust the output to very precise levels and maintain it for the period of activity (Bergsten 1974; Rowell 1974). The stroke volume increase is limited to about 20–25% of the resting levels, and heart rate is the major reason for the several-fold increase in CO (Bergsten 1974; Engelhardt 1977).

The enhanced arterial pressure ensures and forces the tissue to receive greater blood flow by dilating resistance vessels, and as a result of decreased peripheral resistance (Bergsten 1974). This process perfuses organs to an optimum level necessary for the sustained activity, and thereafter the pressure declines to a fairly stable level. The precise mechanism and stimuli which lead to the redistribution of blood flow during work are unknown. Such adjustments are probably brought into action to correct the imbalance between blood supply and metabolic demand or possibly a mismatch between blood flow and resistance (Rowell 1983).

The pulmonary system supplies oxygen to the working muscle. Frequency and depth of respiration change to meet oxygen demands of work. Oxygen availability to the muscles has not been considered a limiting factor for animal performance (Upadhyay et al. 1987). Pulmonary ventilation increases to only a limited extent during work and this may limit work over prolonged periods in animals, as in humans (Bye et al. 1983). The reasons relate to inefficiency of gas exchange and respiratory muscle fatigue, as a result of inadequate perfusion when respiratory muscles compete for blood flow with working muscles and thermoregulation (Rowell 1974).

Metabolic Changes in Blood and Muscle

Studies on working zebu and crossbred cattle (Upadhyay et al. 1987), buffalo (Nangia et al. 1980; Upadhyay and Rao 1985; Upadhyay 1988) and exercising horses (Rose and Hodgson 1982; Rose et al. 1980), and sheep (Bell et al. 1983) have shown that large and rapid metabolic and haematological changes take place in blood as a result of activity. Blood pH may increase over many hours of work. Studies have suggested, however, that the changes are not great enough to require the animal to stop working after prolonged periods.

Muscle biopsies have indicated that the creatine phosphate (CP) declines more in zebu and crossbred cattle and lactic acid accumulates more in crossbreds than zebu (Fig. 1). Muscle energy is therefore not exhausted fully. Regeneration of CP in the muscles occurs continuously and sufficient CP is available to buffer the ATP and ADP concentration (Dawson et al. 1978). So far no tenable biochemical basis exists to indicate that the depletion of CP is directly responsible for the reduction in muscle tension or fatigue development (Harmansen 1981). Therefore

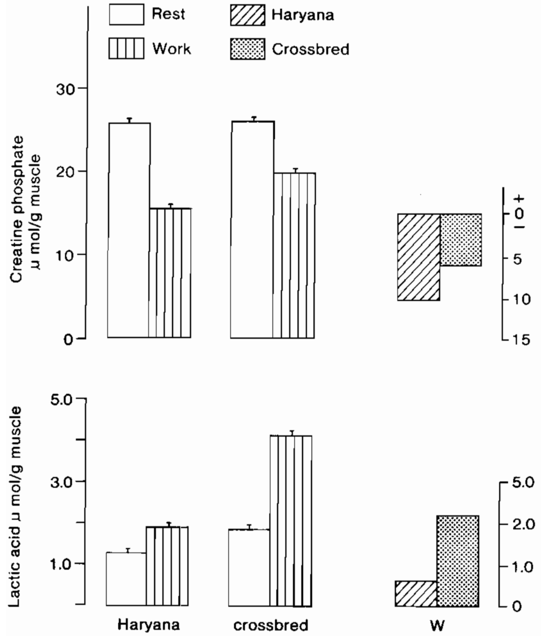


Fig. 1. Effect of work on muscle creatine phosphate and lactic acid in Haryana and Holstein × Haryana bullocks. Mean ± SE (n = 4) absolute levels and changes with work.

muscle fatigue in working animals may not be due to a decrease in CP content.

During work, glycogen, volatile fatty acids and free fatty acids are continuously used in the muscle. Only limited changes in lactic acid (LA) occur in contrast to very high levels observed in muscle. Muscle LA is therefore not fully diffused which may induce the changes related to muscle fatigue (Upadhyay and Madan 1985). Since skeletal muscle tissue has a very high glycolytic capacity, the work level should be adjusted so as to limit the breakdown of glycogen and concomitant production of lactate and hydrogen ion to avoid destruction of acid labile cell organelles. Thus, animals should be worked at slow speeds, say 6 km/hour or less, to avoid excessive production of lactate and hydrogen ion in muscles.

Energy Demand and Supply

Free fatty acids (FFAs) are the major source of chemical energy during prolonged exercise of moderate intensity (Dole 1956; Newsholme 1981). Three major sources (adipose tissue, intramuscular triacylglycerols, and circulatory triacylglycerols) supply FFAs for utilisation in muscle. Studies on exercising horses (Rose et al. 1977; Lucke and Hall 1980) and sheep (Leng 1985) have indicated that the FFAs are mobilised from these sources to meet energy needs. About 50–60% of the supply is from extramuscular depots in exercising dogs (Paul and Issekutz 1967) and people (Havel et al. 1967), and that remaining is contributed by the intramuscular triacylglycerols (Costill et al. 1973; Essen et al. 1977).

During exercise adipose tissue blood flow increases several-fold in sheep (Upadhyay and Hales, unpublished data), dogs (Bülow 1982) and humans (Bülow 1981). The fatty acids are released from adipose tissues in association with plasma albumin (Bülow 1983). The increase in blood flow has been demonstrated to enhance the FFA mobilisation during exercise. This association with albumin increases enormously the amount of FFAs that can be transported but, since the free concentration is very low, it limits the rate at which FFAs can be taken up by muscle (Newsholme 1981). The fuel availability in marathon runners has been implicated in poor performance (Gollnick 1977; Davies and Thompson 1979). Studies on fat-depleted sheep carrying weight on their back have also revealed that adipose tissue depots are perfused to derive FFAs, and depleted animals depend on limited adipose tissue depots for energy during work (Upadhyay and Hales, unpublished data).

A similar situation is expected in underfed oxen ploughing fields and covering 40–50 km/day in 6–8 hours continuously for several weeks in a cropping season. Inadequate feed availability prior to the monsoon season leads to poor physical condition of animals. Under such conditions work is performed over prolonged hours at the expense of adipose tissue depots mainly, and to a lesser degree to stored glycogen. It is important, therefore, to make available diets rich in both fat and carbohydrate prior to and during work periods to sustain work for longer periods, or if output is to be improved (Wachirapakorn and Wanapat 1989). Farmers in India often feed mustard oil, butter oil (ghee), milk, rice bran and treacle to oxen in a cropping season depending on the extent of use. The farmers I spoke to believed that such practice is advantageous.

Regulation of FFA mobilisation from fat depots is a possibility which may be explored to enhance output if animals of better genetic make-up are selected and trained. Training has a profound effect on FFA mobilisation in humans (Holloszy and Booth 1976) and rats (Buckowiecki et al. 1980). Both sex (Despres et al. 1984a) and genetic (Despres et al. 1984b) differences in lipolytic activity have been observed, and training improves the preferential utilisation of FFAs more in males than females (Despres et al. 1984a).

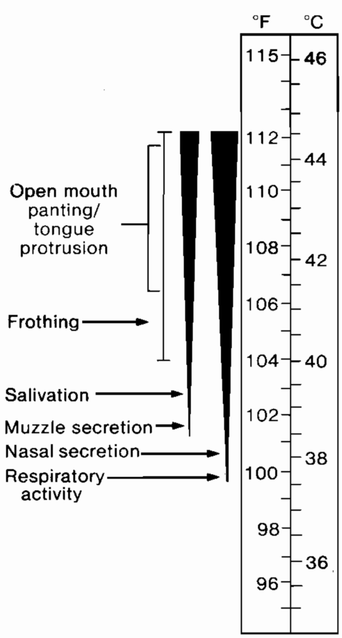
Mechanisms for Dealing with Heat Loads

Muscle activity obviously produces work, but it also produces far more energy in the form of heat than work. Many chemical reactions proceeding in the body simultaneously liberate energy by chemical transformation, and adenosine triphosphate (ATP) splits into smaller molecules, namely adenosine diphosphate (ADP) and phosphate. This process liberates several thousand joules of energy required for muscle contraction (Curtin and Woledge 1978; Marechal 1981). Only a part of this energy is used by contractile proteins and the rest is set free in the form of heat to be dissipated by various physiological processes.

Most work is carried out in environments cooler than the body (Goe 1983), and animals lose heat by evaporative and nonevaporative channels in an effort to maintain a constant temperature, or to contain temperature within physiological limits. Work in heat poses several problems for both oxen (Upadhyay et al. 1987) and buffaloes (Upadhyay 1988). As ambient temperature increases the gradient for nonevaporative heat loss decreases, but high heat content of the body allows net outward flow of heat by nonevaporative processes (Taylor 1981; Finch 1985). Movement of animal wind velocity by disturbing the insulatory coat of skin helps the animal system to lose heat evaporatively at a rate equal to 8–15 times their metabolic rate (Robertshaw and Taylor 1969; Robertshaw et al. 1973), and at a far greater rate than the pulmonary ventilation systems can achieve.

Responses of small and large animals to heat and exercise have been discussed by Taylor (1981) and Yousef (1981). All mammals increase their body temperature during activity, though working buffaloes increase body heat more than crossbred and zebu cattle (Upadhyay 1987). All species deal with higher heat loads of work and environment by all four mechanisms (Taylor 1981): (i) evaporation from the nasal mucosa, (ii) evaporation from the buccal surfaces and the tongue, (iii) evaporation from the skin, and (iv) hyperthermia and deferred dissipation of heat.

If the environmental heat loads are not great enough, as in early and late hours of the day in summer and in winter, inward heat flow from the environment will be less, hence animals will not be unduly distressed. Increased evaporation from nasal



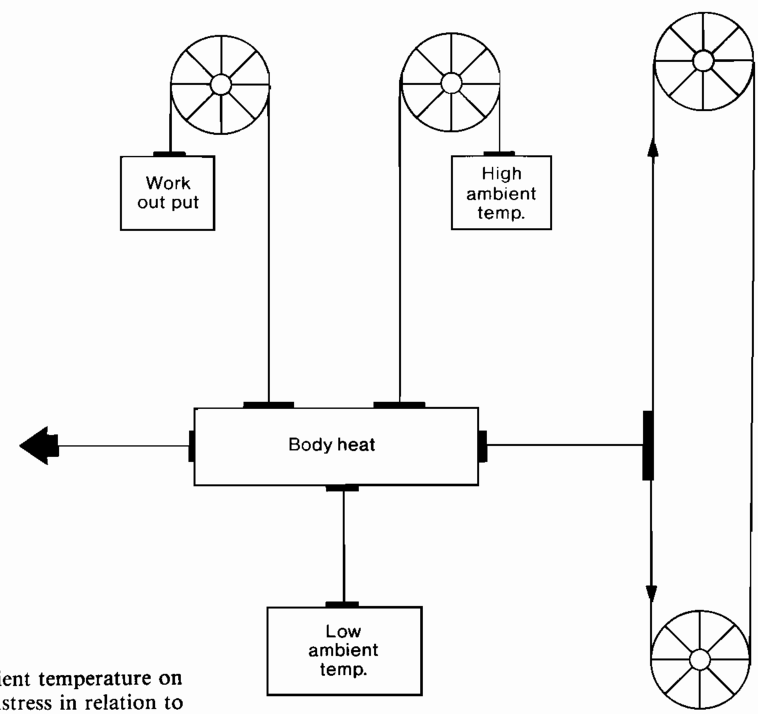


Fig. 2. Effect of work and high ambient temperature on body heat, respiratory activity and distress in relation to temperature.

mucosa during work in cattle and buffaloes handles about 2–3 times the heat produced during rest. Inability to get rid of heat by evaporative and nonevaporative means causes a rise in body temperature, and 'second phase'-type panting associated with hyperthermia. This situation is similar to dogs (Hales and Dampney 1975), sheep (Hales and Webster 1967), taurus cattle (Hales and Findlay 1968) and can be seen in taurus zebu crosses (Upadhyay and Madan 1985; Upadhyay et al. 1987) and buffaloes (Upadhyay and Rao 1985; Upadhyay 1988) over prolonged hours of work (Fig. 2). In the 'second phase' of breathing, inhalation is through the nose and mouth. Buccal surfaces and tongue become important sites for evaporative cooling. The tongue protrudes in some cases to increase surface area for forced convective cooling, and salivary secretions provide enough water to permit heat loss. Evaporation from respiratory passage, buccal and tongue surfaces enables animals to double the rates of evaporation obtained from the nasal mucosa alone (Taylor 1977). Inability to handle heat load by these additional processes at high ambient temperature raises body heat beyond the limits that the brain can tolerate. Despite capacity to maintain the brain temperature below that of the rest of the body, the elaborate counter-current cooling mechanisms at the cavernous sinus and direct conductive cooling of the base of the brain by heat loss to the cavernous sinus fail (Baker 1980; Chesy et al. 1985). In such cases animals become overexcited or giddiness appears, and the animals stop working (Chesy et al. 1985; Upadhyay and Madan 1985).

Heat Content and Muscular Activity

During work the body serves as an effective heat sink for muscle due to a gradient in muscle (Tm) and core temperature, but as core temperatures rise, heat flow to the core decreases (Faulkner 1981). During prolonged work in hot dry or hot humid conditions, rectal temperature (Tre) of cattle and buffaloes increases continuously (Chesy et al. 1985; Upadhyay and Madan 1985; Upadhyay and Rao 1985). After about 3–4 hours of work animals may attain a Tre of 42–43°C associated with Tm of 44–45°C, and exhibit distress symptoms. Most vital functions and all biological processes are stressed by this high temperature. In muscle, increased temperature affects crossbridging activity, rate of ATP utilisation, rate of rephosphorylation of ADP, AMP, glycolysis, oxidative phosphorylation and uptake and removal of metabolites in muscle (Astrand and Rodhal 1977; Faulkner 1981). High Tm and concomitant increase in lactic acid level and reduction in creatine phosphate affect the rate limiting enzyme phosphofructokinase (Sahlin 1978; Newsholme 1981), contractile property (Close 1965; Close and Hoh 1968), and increase excitability and conduction of nerves and muscle, and speed of contraction (Faulkner 1981).

Optimum Tm of 28–32°C for sustained isometric voluntary contraction at one-third (Clark et al. 1958) and two-thirds of maximum have been reported. Fatigue occurs both at muscle temperatures below 25°C and above 40°C due to nervous or neuromuscular transmission interference (South 1961). Fatigue at low Tm has been attributed to a decrease in muscle tension due to a decreased threshold for excitation and to the effects of temperature on enzymatic activity. At high temperatures it may occur either because of increased mitochondrial ATP activity or inhibition of phosphofructokinase or both (Newsholme 1981).

Muscle Fatigue

Muscle in the process of contraction uses ATP as its fuel. Depending on the level of work ATP is supplied by aerobic and anaerobic processes in the muscle. Draught animals working at lower rates generally do not exceed the aerobic limits, but moderate to heavy work involves both processes at higher rates. As skeletal muscles have very high glycolytic activity which may be initiated immediately, both anaerobic and aerobic systems produce ATP simultaneously for the process of muscle contraction at moderate to high levels of activity (Newsholme 1981).

Muscle fatigue during sustained work or after a burst of activity has been attributed to either accumulation of waste products or depletion of energy-mediating processes. When all muscle energy is exhausted the muscle is unable to expand the small amount of ATP required for relaxation (Cholvin 1970). However, this may happen only in extreme cases after physiological contracture or after a burst of muscular activity. In general, this does not happen in draught animals and energy in the form of ATP is supplied continuously by both aerobic and anaerobic processes. The lactic acid produced in muscle as a result of anaerobic breakdown of glycogen is not removed quickly, and contributes to fatigue by lowering pH and affecting enzymatic processes. The lactic acid content in muscle in bullocks performing heavy work over prolonged periods in heat has shown that fatigue is more probably related to accumulation of lactic acid (Fig. 1) and inadequate neutralisation in muscle than to energy exhaustion.

Fatigue is a complex process and occurs due to change in the 'internal milieu' reflective of inadequacies of cardiopulmonary and neuromuscular integration, and is complicated by the thermoregulatory process. The fatigue may occasionally occur at muscular function as a result of diminution in acetylcholine after repeated contraction. This happens rarely; usually the levels do not fall sufficiently to fail to depolarise the motor-end plate (Goll et al. 1984). Repeated nerve stimulation over long periods has also been shown to exhaust calcium in sarcoplasmic reticulum which affect the formation of myosin molecule. Disturbed ion balance in muscle, due to decrease in efficiency of Na-K pump over prolonged work, creates onset of fatigue (Duncan 1978; Haralambie 1981).

Incoordination and movement inhibition observed in bullocks and buffaloes may be attributed to neuromuscular fatigue, which may occur prior to contractile fatigue or as a result of exhaustion of calcium or energy in the muscle. Since the physiological processes are complementary within limits, the commissioning of various processes protect muscle from irreversible damage or physiological breakdown. Work animals can be declared fatigued on the basis of various physiological and behavioural manifestations (Upadhyay and Madan 1985), and rest pauses may be essential to protect the animal from any health problems related to overstress. Frothing, dribbling of saliva and tongue protrusion are commonly seen in overstressed work animals. Stepping of animals, uncoordinated movement and inhibition of progressive movement may be recognised either from the side or the rear, and animals should then be stopped for a rest.

Work-Rest Cycle

Farmers in tropical countries use animals for 6-8 hours with several intermittent rest pauses, or the work may be restricted to a single session. The most prevalent practice is to use animals early in the morning from 5 or 6 a.m. until about noon, avoiding the hot period of the day (FAO 1972). Farmers should avoid continuous and prolonged use of the animal for heavy work. Overrunning at high speeds for several days, which may exhaust or overstress animals and adversely affect farm operations or field work, should be avoided.

Considering the change in physiological reactions and exhibited distress symptoms, which are symptoms of fatigue, it is essential for the user to provide rest pause(s) between prolonged hours of work and 1 or 2 days rest after several days work. The exact number of rest pause(s), however, depends upon the extent of use, type of work, environment and other factors limiting work.

Various physiological functions stressed due to heat stored during work need special attention, as the capacity to lose heat in panting animals is lower than in animals dependent on sweating. The ability to dissipate heat is more pronounced in tropical breeds of cattle than temperate cattle, their crosses and buffaloes (Moran 1973). Sweating, pulmonary evaporation and open-mouth panting help the working animal to dissipate heat to a limited degree. Therefore, adequate measures need to be taken during rest, if prolonged work is required from animals for several weeks, to bring down body temperature to prework or near rest value before the next session of work begins. Buffaloes specifically need to be protected from radiant heat as they increase body heat more than other animals and react excessively (Upadhyay 1988), and physiological reactions may not return to preexercise resting levels for more than 5-6 hours. Therefore, such animals not only require protection but also require long rest periods, wallowing, or water sprinkled on the body. Animals unable to recover the physiological functions to a normal level during rest periods accumulate the effects of work, as the work progresses over days and weeks in a season. Physiological reactions of lower magnitude will completely disappear during the intervals between work days, and animals are likely to recover fully. But if the rise is higher, the interval between two sessions may not be enough to recover. Hence the interval between two sessions must be long enough to ensure complete recovery.

No specific research attempts have been made to indicate the suitable work-rest cycle, and number of rest breaks. The disjointed and variable information available from farmers based on practices followed have been considered to furnish guidelines for a work and rest cycle (Fig. 3). Organised rest pauses during work reduce level of stress, delay fatigue onset and the animal performs work with ease without any harmful effect on health. The rest pause suggested is 30 or 60 min in a work session. Light working (tillage or furrowing of land) at low temperatures during early hours of the day raises physiological reactions only

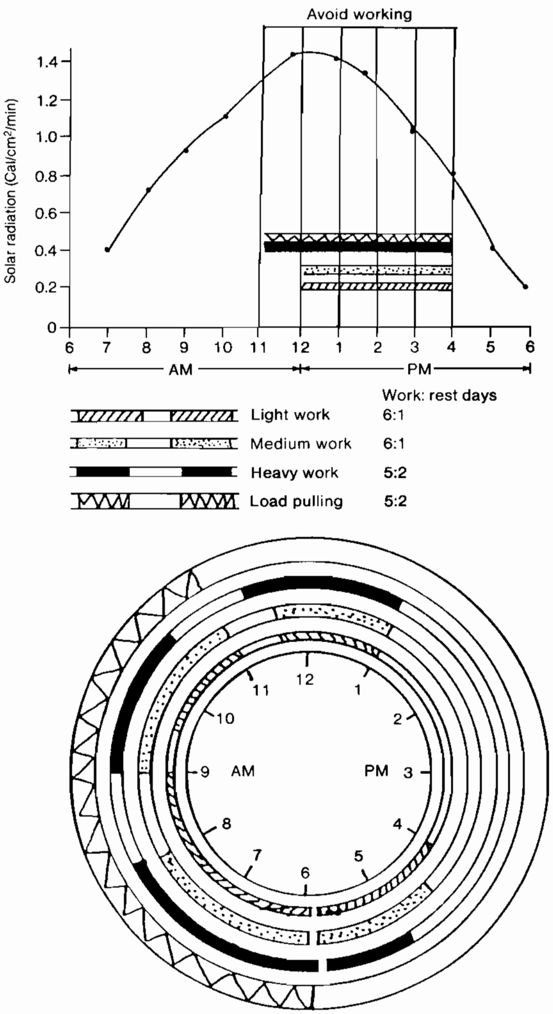


Fig. 3. Work-rest cycle for working animals in tropical climate.

moderately, and a 30 min rest period reduces cardiopulmonary activity to satisfactory levels and reduces body temperature by about 0.5C°, depending upon local conditions. During heavy work, provision of a 60 min rest period will lower the physiological reactions moderately, and animals will be able to sustain work for about 2–3 hours longer. At the end of 1 hour rest, though, the animals will not recover fully, and will begin work at high physiological reactions, but further rise over prolonged hours in physiological reactions will be less. Animals involved in work of moderate to heavy intensity do not recover physiological processes even after a rest pause of 6–8 hours, and fatigue effects accumulate; such animals should be used for 2–3 days and given 1 day rest before doing more work; rest days should be regulated to 2:1 or 3:1 depending on level of work and need.

Animal-Drawn Implements and Harnesses

Animal-drawn implements used by farmers consist of plough and harrow for land preparation, planter or seeder for planting and animal-drawn vehicles. These implements are generally found in places where the use of draught animals has a long tradition, such as India, China, African countries and Southeast Asian countries. The long history of these implements has resulted in a variety of designs, modifications, harnesses and yoking systems. The size and shape of these implements often vary from region to region depending on cultural practices, soil type, animal species used, etc. But the basic functional structures are similar, and there are no radical differences among the implements meant for similar operations. These implements are made by local blacksmiths and carpenters.

Although these implements have been evolved by centuries of practical experience and need, and have stood the test of working in particular agroclimatic zones, most of these traditional implements do not make optimal use of the animal energy and cause considerable strain to both the animal and person at work (Goe and McDowell 1980). Oxen and the farmer have to walk about 50–60 km/ha to plough fields (Yadav 1987). Uneven surfaced and ploughed land reduce speed at work and consume more energy of farmer and animal. Wheeled tool carriers have been developed (Bansal and Thierstein 1982; Lal 1986; Starkey 1988) and improvements in designs of other farm implements have also been made (Howard 1980; Sarkar and Farouk 1983; Srivastava 1987; Starkey 1988). Some of these developments have not been accepted by farmers (Munzinger 1982; Starkey 1988), either due to limited utility and high cost or discomfort to animal at work or both. Complicated fabrication, requirement of spares, availability of know-how have added to the rejection of these modified farm implements (Goe 1983; Starkey 1988).

Yoke, harnesses and hitching devices for various implements often vary from animal to animal. The existing devices require the animals to exert a greater tractive effort than is actually required for pulling implements (Howard 1980; Goe 1983). Limited efforts have gone into improving them with the specific intention of distributing load at different points, and to provide comfort to the animal.

Wearing a collar which spreads the load more evenly around the animal's shoulders improves the efficiency about 3% (Lawrence 1983). Similarly a lightweight harness with three-point neck collar and yoke combination improves draught output by 10–15% over the traditional yoke (Singh and Ojha 1987). But the animal's reaction to these devices has not been evaluated for fatigue or discomfort. Therefore, work to optimise and improve production and which offers more comfort and distributes load on the animal needs to be done, and tested.

Summary and Conclusions

Most draught animals do not perform work to their full capacity, so improvements need to be made in the complete system including animal, implements and other factors limiting performance. Within the capability of farmers, improvements can be achieved by proper selection, training, feeding and management of animals. The animal size, body weight, conformation, leg coordination, structural defects, animal temperament and training must be considered during selection. Capacity for work can be further improved by selecting proper and matching implements with efficient yoke and harnesses.

Climate is the main constraint which limits work, stresses the physiological systems and induces fatigue. Therefore, adequate and timed rest periods must be given to the animal to recover. Accumulation of lactic acid in muscle, heat in the body and excessive dehydration affect the work output. The strenuous work requiring long travel or heavy load pulling should be followed by long rest periods for complete recovery and rehydration. During this rest period animals must be optimally fed fat- and carbohydrate-rich feeds and water ad libitum to rehydrate. To avoid climatic stress, animals should be adequately protected, worked in early and late hours of the day, allowed wallowing in the case of buffaloes or sprinkled with water. Such practices improve work performance, delay fatigue onset and cause early recovery from work stress.

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Living with, and Overcoming Limits to, Feeding Value of High Fibre Roughages

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Abstract

Any prediction of the likely performance of animals receiving particular types of crop residues depends on understanding the agronomic and postharvest variables affecting the inherent qualities of the straw. The attributes of cereal plants which determine feeding value of their harvest residues have been examined in numerous studies, the essential outcomes of which are reviewed. That basic variability is also reflected in the differences in effectiveness of supplements or of treatments, such as with urea-ammonia, aimed at improving the utilisation of the straw as a diet component. The quality of the straw and the interactions with other dietary ingredients affect intake, digestibility and the balance of nutrients provided. This paper discusses the bases on which classification of crop residues into feeding value categories may be made. The interrelationships between intake, digestibility and nutrient balance are explored.

Introduction

HIGH fibre roughages, available in large quantities, are obligatory components of many feeding systems for ruminant livestock. This is particularly true of the animals used in cropping systems relying on draught power. Though other products may be expected of draught power animals, the capacity to grow, reproduce and produce milk is often exploited on an opportunistic or poorly planned basis. If improvement in performance of the animals is desired by the farmer, accomplishment will largely depend on better matching of periods of special nutrient requirements with planned allocation of appropriate feed components.

The feeding value of the crop residues, particularly straws, included in the feed year calendar is limited but highly variable. Some straws will not support the nutrient intakes required for survival, others just permit maintenance of liveweight, while some provide a reasonable basis for development of diets supporting weight gain and modest levels of production. The capacity to fulfil a desired year-round production program and essential draught power schedule depends on optimising cycles of liveweight change of various classes of animal. Body reserves available at critical times provide a back-up in meeting demands not readily met by the currently available feeds. This requires the ability to predict for a range of purposes the feeding value of the crop residues alone or in combination with other materials.

Any prediction of the likely performance of animals receiving particular types of crop residues depends on understanding the agronomic and postharvest variables affecting the inherent qualities of the straw. The attributes of cereal plants which determine feeding value of the harvest residues have been examined in numerous studies. That basic variability is also reflected in the differences in effectiveness of supplements or of treatments, such as with urea-ammonia, aimed at improving the utilisation of the straw as a diet component. The quality of the straw and the interactions with other dietary ingredients affect intake, digestibility and the balance of nutrients provided. This paper discusses the bases on which classification of crop residues into feeding value categories may be made. Feeding value for a particular purpose is determined

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relative to the specific nutrient needs of the animal. Since variation in feeding value may arise because of differences in intake and/or nutrient yield per unit intake (nutritive value), the interrelationships between intake, digestibility and nutrient balance among digestion end-products with straws are examined.

Feeding Value

While cereal straws have a reputation for low nutritive value, in vivo digestibilities of dry matter range from 35 to 60% (Doyle et al. 1987). Recorded intakes by cattle and buffalo are from 1.2 to 2.9 kg/100 kg liveweight (Pearce 1986). In many cases where performance of animals fed cereal straw-based diets has been reported, the source and characteristics of the straw have been poorly described. Further, the magnitude of the excess of feed offered in voluntary feed intake studies, if described at all, varies widely between experiments, permitting differential degrees of selection among the plant constituents. Some standardisation or at least better description of procedures has been an important step needed in making progess in identifying the factors affecting feeding value of straws. In 38 studies with cattle fed rice straw under reasonably consistent conditions of experimental method, the compound effect of variation in intake and digestibility, as digestible organic matter intake (DOMI) varied over a five-fold range. On the poorest materials, animals could not survive for more than a few weeks, the period depending on body reserves. On the best materials quite respectable liveweight gains were made or could be expected. It is significant that where tested in the same experiments, those straws of poorer feeding value frequently showed less significant improvements with urea treatment, and animals responded less to supplements intended to enhance rumen fermentation rates.

The differences between straws could in some cases be assigned to possible causes including genotype, agronomic and edaphic factors, crop management practices and harvesting procedures. However, the tendency for experimenters to use straw from unknown sources often thwarts attempts to define the materials in these terms. More usually, some chemical analysis will have been undertaken as a basis of description of the straw used. Correlations of feeding value with chemical components have been attempted but residual variance is high. The usefulness of this is to provide a broad separation of a continuum of straws into three classes which can be described as:

(i) those relatively low in residual cell contents and high in fibre, usually more highly lignified, of low in vitro digestibility (30–40%) and low intake, usually not greatly improved by urea treatment;

(ii) those relatively high in residual cell contents and lower in cell wall content, not as extensively lignified, supporting higher intakes and digestibilities (IVOMDs of 50–60%); and

(iii) those in an intermediate digestibility range (40–50%), with low cell contents but with cell walls of variable digestibility only broadly related to lignin content, with variable improvement associated with urea treatment.

The relationships between intake and in vitro digestibility, and the factors contributing to variability around that relationship, have been sought.

Variation in Morphology of Straws

The key factors directly influencing the digestibility and the voluntary intake of fibrous feeds are the physical properties of the plant parts, the proportions of the different plant parts, the proportions of different cell types in the various plant parts, the relative amounts of cell contents and cell walls in those tissues and the physical and chemical nature of the cell walls.

The morphological composition of cereal straws varies considerably. The proportion of stem may be from 20 to 40% of rice straw. Procedures for harvesting, threshing and storing can alter, usually increase, the content of stem. For the rice plant IVOMD of stem varies from 40 to 75%, that of leaf sheath from 38 to 56%, and that of leaf from 45 to 60% (Pearce et al. 1988). While the digestibilities of the various parts of individual plants are strongly correlated, the factors that limit digestibility have different significance in the various parts. The growth conditions have a major influence in this. Further, the upper parts of the stem may be of higher digestibility in plants maturing under dryland conditions, while the lower stem internodes are of highest digestibility in irrigated systems (Hart and Wanapat 1986). The wideness of these ranges is associated with the roles of leaves and stems in acting as storage units for carbohydrates and protein which the developing grain draws upon during the period from anthesis until grain maturity. It is also affected by presence of any sterile tillers or tillers developing after the removal of the grain, depending on both the genotype and the soil moisture levels.

On the basis of chemical composition, the residual amounts of cell contents is therefore an important component of variability in nutritive value. This in turn is very generally correlated with the differences in the inherent digestibility of cell walls. This follows from the usual pattern of coordinated physiological processes associated with grain filling and maturation of the whole rice plant. In one attempt to provide an agronomic basis for descriptors of the nutritive value of the straw (S.J. Kent and G.R. Pearce, pers. comm.) digestibility of stem and leaf have been related to the grain yield and harvest index of different rice cultivars under different environmental conditions. Approximately 65% of the variability in digestibility can be associated directly with variability in these two agronomic descriptors, but the residual variability has not been attributed to any specific genotypic or environmental factors. Digestibility of dry matter and in some instances organic matter of rice straw varies with the extent of deposition of silica, particularly in leaf, which is variable between genotypes and growing conditions (Juliano 1985, 1988).

Structure and Composition of Cell Walls

The cell walls are composed of a cellulosic fibrillar phase in a matrix of noncellulosic polysaccharides and some protein. In secondary thickening of the cell walls lignin is present. During maturation there is a rapid decline in the digestibility of cell walls, this generally being more rapid and of greater magnitude for stem than for leaf. The polysaccharides show compositional changes and increasing crystallinity which are only broadly correlated with decreasing digestibility. However, lignin progressively increases in concentration and the monomer composition changes, so that with maturity there is less of a component released by polysaccharide hydrolase (Neilson and Stone 1987). The cross-linking of lignin to polysaccharides results in changes not always simply related to lignin concentration. These linkages have been regarded as the prime target for modifying cell wall digestibility through alkali treatment, conventional plant breeding or biotechnological approaches with the plant, and through application or modification of the capabilities of microorganisms such as the white rot fungi or the rumen anaerobic fungi. However, in respect to the latter ideas, the capacity of the organisms to produce a 'lignase' does not mean that the organism, given access to alternative sources of nutrients, will preferentially attack the lignin-polysaccharide bonds.

Intake of Cereal Straws

There is a very general relationship, within cereal types, between voluntary intake of straw (kg/100 kg liveweight) and its in vitro digestibility ($R^2 = 0.37$ for 83 studies with small ruminants; $R^2 = 0.43$ for 35 studies with large ruminants). The large residual variability in intake around this relationship has been examined and appears to derive from two main sources. First there are plant characteristics which affect intake through palatability and edibility factors poorly related to digestibility. Also confounded in this is the variation in the conditions under which the materials were fed, such as the level of excess offered. Second, animal characteristics affecting energy drive (for example, condition score of the animals; Djajanegara and Doyle 1989), acceptability and rate of eating can be discerned in some studies, but poor description of animals used in experiments prevents isolation of the influences of these components.

Doyle and Chanpongsang (1989) and Doyle and Panday (1989) have related acceptability and voluntary intake of straws to eating rate and found a relationship of these to the physical strength of the straw (resistance to grinding) which does not parallel the differences in in vitro digestibility. Thus while stubble may be of higher digestibility than the straw from the same rice plant, intake by cattle of the straw may exceed that of the stubble (Wanapat and Kongpiroon 1988). The leaf fraction in that straw appears to be more acceptable than the more highly digestible stem fraction of the stubble.

A pattern of relationships between digestibility and voluntary intake of untreated rice straws has been derived from studies with cattle and buffalo and is presented in the form of a probability distribution (Fig. 1). Methods of classification or recognition of the attributes which place particular straws in zones of high or low probability of the animal achieving high intakes of straw are now being pursued as components of a feeding strategy planning model.

Pretreatment

NaOH, CaOH, and ammonia pretreatment have been successfully employed in experimental and some commercial circumstances to increase

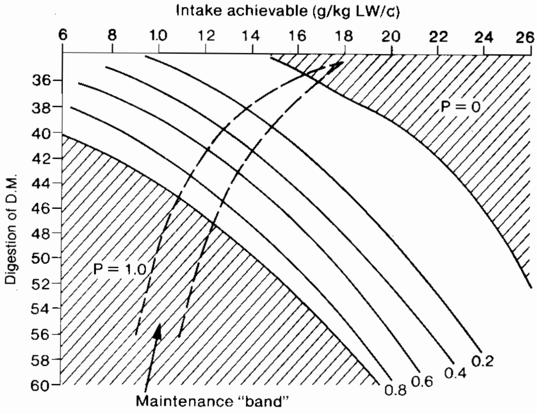

Fig. 1. Probability distribution for intake achievable with native straws: digestibility as base for prediction (108 experiments with cattle; 32 experiments with buffalo).

digestibility and intake of straws. These procedures are inappropriate in village conditions so that the prospects for cheaper, simpler, safer but generally less effective pretreatment with urea as a source of ammonia have been extensively explored. While intake and digestibility are usually improved by urea-ammonia treatment the improvement in digestibility is often small (2–10 units of digestibility) and a large component of this is matched by urea supplementation (Egan 1986a). There is little evidence that major changes in the chemical bonding of lignin to carbohydrates in cell walls take place. Nonetheless, intake of digestible organic matter is often substantially increased. The extent of the increase is roughly correlated with the inherent digestibility of the native straw. From 12 studies with cattle, where standard pretreatment was used, the improvement in intake is indicated by the following example equations:

$$IT = 1.21\,IU - 0.74\ (R^2 = 0.63)$$

$$IT = 0.38\,IVOMDU - 0.28\ (R^2 = 0.71)$$

where *IT* is intake of treated straw (kg/100 kg liveweight), *IU* is intake of untreated straw, and *IVOMDU* is the in vitro digestibility of organic matter (%) of the untreated straw.

There are insufficient data of a standard consistent with the development of a probability matrix for relationships between digestibility and intake of treated straws, but initial comparisons indicate that the treated materials fit alongside the data for N-supplemented straws.

Supplementation

When straws are fed as a base roughage in diets of mixed components, all types of associative effects are found. These include:

- enhancement of digestion rates where nutrients limiting for microbial activity are provided;
- depressed rates of digestion of fibre where ruminal pH is depressed and persisting NH_3 concentrations are low;
- substitution where more acceptable and more readily digestible energy components depress straw intake;
- elevation of intake where the conditions for dynamic processes of breakdown and removal of fibrous particles are improved; and
- improvement in performance directly associated with source nutrients not degraded in the rumen.

In general the lower the digestibility of the straw the more likely are the adverse effects of substitution and the depression of fibre digestion when readily fermentable energy sources are given. Provision of supplements providing specific nutrients limiting for microbial growth have less effect with straws of lower inherent digestibilities, probably because the parallel limiting factor is the accessibility of hydrolysable cell wall constituents. Despite this the benefits of the supplement in terms of overall nutrient intake and balance may mean less liveweight loss. This, in a year-round feeding program, may be of vital importance to the subsequent performance of the animal. Thus straws of higher digestibilities (50% and above) can permit excellent responses to the provision of balancing nutrient sources (Leng 1987; Dixon and Egan 1987), in some cases showing up to 30% increase in the rate of organic matter digestion and 30–40% increase in intake. However, in vivo digestibility may not always show dramatic increases, possibly because of reduced residence time of roughage particles in the rumen associated with greater intakes (Egan et al. 1986).

The following example equations reflect the pattern of effects of N supplementation on digestibility of straw at constant intake, and the effect of ruminally degradable N sources on voluntary intake with a range of straws fed in 23 experiments with cattle:

$$DN = 1.093\,DU + 0.21\ (R^2 = 0.63)$$

$$IN = 1.18\,IU - 1.93\ (R^2 = 0.55)$$

where *D* is in vivo digestibility, *DU* being that of the unsupplemented straw and *DN* that in the presence of ruminally degradable N supplement; and *I* is voluntary intake with 20% excess feed offered, N and *U* being N-supplemented and unsupplemented respectively. Other sets of equations relating response to chemical and physical characteristics of the straw and the degradability of the supplement are being developed from published data, particularly that derived from studies undertaken throughout the Asian-Australasian Fibrous Agricultural Residues Network.

Feed Year Strategies

The value of the crop residues within year-round feeding programs is a function of the objectives of the livestock owner, and the ability to match feeds available at any time with the feed requirement for particular patterns of liveweight change. Optimising among the alternative feed resources which are available needs to take account of different costs particularly those expressed as time and effort for the limited labour force available. This requires predictions of immediate and later consequences of incorporating a particular definable class straw, fresh or stored, treated or otherwise, with or without supplement, into a given animal's yearly cycle of production. Liveweight, liveweight gain and condition either determine or correlate with the performance capabilities in reproduction and draught power. An Expert System model for feed use optimisation is being developed which can accommodate alternative forms of input on which predictions of liveweight pattern and performance can be made for a range of feeding options and animal production requirements. The strategy for optimisation may involve modification of some expectations of the animals as well as of the feeding system. However, the model requires the translation of principles and accumulated qualitative knowledge into quantitative relationships.

This paper has indicated the work done on classification and quantification in relation to the facts that 'all straws are not equal' and that different responses to treatment and supplementation can be expected. The responses at any one time can have different values for animals in different phases in their productive cycles and the full value can be delivered at a time distant from the particular feed action taken (Egan 1986b).

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Production from Faunated and Defaunated Ruminants on Straw-Based Diets

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Abstract

Poor utilisation of straw-based diets by ruminants is due partly to an inefficient rumen ecosystem and to an imbalance in the products of rumen fermentation. Removing protozoa from the rumen (defaunation) has previously been shown to increase the efficiency of rumen fermentation and was one of the strategies investigated under an ACIAR-supported project entitled 'Developing technologies for increasing the efficiency of straw utilisation by ruminants.' Studies conducted under this program with sheep and buffalo clearly demonstrated that production (liveweight gain and wool growth) from straw-based diets was enhanced by removing the protozoal population from the rumen. These responses appeared to be due to an increase in the digestibility of straw and to an increase in the post rumen availability of protein (microbial and dietary).

Introduction

CEREAL straws are poorly utilised by ruminants. Consequently a number of strategies have been developed to increase the efficiency of utilisation of straw-based diets. These include: (a) the pretreatment of straw to increase the digestibility and 'nutrient value' of the straw; (b) the use of dietary supplements to either correct nutrient deficiencies in the rumen that may limit the fermentation of straw or to provide 'rumen bypass' nutrients to balance the products of rumen fermentation; and (c) manipulation of the microbial population in the rumen to increase the efficiency and extent of fermentation. Under an ACIAR-funded project a number of these strategies were investigated. However, only the results from studies involving the removal of protozoa from the rumen (defaunation) are presented in this paper. Previous studies conducted at the University of New England (Australia) with sheep and cattle (given good quality diets) demonstrated that production was enhanced by removing protozoa from the rumen (Bird and Leng 1978, 1984, 1985). Results from earlier studies investigating the changes in rumen function associated with defaunation suggested that defaunation may also be beneficial to animals given straw-based diets. To understand why defaunation might enhance ruminant productivity, it is necessary to consider the role of protozoa in the rumen.

Protozoa in the Rumen

The three major groups of microorganisms that are responsible for the fermentation of ingested plant material in the rumen are: bacteria, protozoa and fungi. These organisms coexist in a dynamic equilibrium, which means that one group cannot be influenced independently from the other two. Protozoa and bacteria compete for the same substrates in the rumen and protozoa engulf and kill bacteria (Coleman 1975), so that if protozoa are removed from the rumen the bacterial population

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increases. A similar relationship apparently exists between the protozoa and fungi. The concentration of viable zoospores (motile stage in the life cycle of the fungi) in rumen fluid collected from defaunated sheep was two- to five-fold higher than in rumen fluid collected from faunated sheep given high roughage diets (Table 1). The changes in rumen function associated with defaunation are therefore a balance between the protozoal activity which is lost and the bacterial and fungal activity which is gained. Therefore it is pertinent to consider the role of bacteria, protozoa and fungi in microbial protein synthesis and fibre digestion in the rumen.

Table 1. Concentrations of viable zoospores cultured from rumen fluid collected from faunated and defaunated sheep (Bird and Leng 1985).

	Viable zoospores ($\times 10^{-3}$/ml)	
Diet	Faunated	Defaunated
Wheat straw	7	16
Ammoniated wheat straw	4	12
Native pasture	7	30

Microbial Protein Synthesis

The rumen protozoa are proteolytic, producing ammonia and amino acids as end products (Warner 1956). Their N metabolism is based primarily on the digestion of engulfed bacteria (Coleman 1975) and plant proteins (Coleman 1983). The utilisation of these protein substrates is inefficient as a significant proportion of the total amount of protein engulfed by the protozoa is excreted as amino acids (Coleman 1975). Degradation of protein or amino acids of microbial origin reduces the net yield of microbial amino acids available for intestinal digestion. Further, a large proportion of the protein incorporated in the biomass of protozoa in the rumen may not be available for digestion in the intestines. There is now a considerable amount of evidence (see Bird and Leng 1985) which indicates a low outflow rate of protozoal cells from the rumen in relation to their concentration in the rumen. The studies of Leng et al. (1981) and Leng (1982) demonstrated that a large proportion of the protozoa complete their life cycle in the rumen. The apparent turnover of protozoal protein in sheep was calculated to be 67% of the total protein synthesised by protozoa with only 33% of the protein in the protozoal biomass leaving the rumen (Leng 1982). The synthesis of protozoal nitrogenous compounds and their breakdown in the rumen therefore contribute considerably to the N recycling within the rumen. With respect to the protein economy in the animal, therefore, the obvious advantages in replacing the protozoal population with bacteria are:

(1) a greater utilisation of nonprotein nitrogen in the rumen,
(2) a reduction in the amount of dietary protein degraded in the rumen, and
(3) an increased yield of microbial protein from rumen fermentation, and increased availability of microbial protein for digestion in the intestines.

These advantages have been confirmed by studies designed to measure the intestinal flow of protein in faunated and defaunated sheep given high quality diets (Table 2). Defaunation was associated with a 26% increase in the total flow of nonammonia nitrogen at the intestines. This response was due to a 19% increase in the flow of microbial protein from the rumen and a 7% increase in the amount of dietary protein escaping degradation in the rumen.

Table 2. A comparison of flows of microbial N and nonammonia N (NAN) into the intestines of faunated and defaunated sheep.

	Flow of N at the intestines (g/day)		Benefit from defaunation
	Faunated	Defaunated	(%)
Total NAN*	21.0	26.4	26
Microbial NAN*	14.6	17.4	19

* Mean values obtained from numerous authors.

Fibre Digestion

Although a number of enzymes capable of degrading plant cell walls have been isolated from rumen protozoa, Hungate (1975) has suggested that the amount of cellulose digested by the protozoa in the rumen was likely to be small in comparison with that digested by bacteria. Currently there is no precise quantitation of the role played by fungi, however, these organisms have been shown to be actively cellulolytic and capable of colonising and growing on plant fragments (Bauchop 1981). These properties taken together with the extent of rumen populations observed on plant fragments in animals receiving high fibre diets indicate a significant role for the fungi in fibre digestion. It is apparent therefore that replacing the protozoal population with bacteria and fungi should result in an increase in the rate and extent of fibre digestion in the rumen.

Studies with sheep (University of New England, Armidale, Australia) and buffalo (Central Institute for Research on Buffalo (CIRB), Hisar, India) were established to determine the effects of defaunation in animals given straw-based diets.

Results and Discussion

In sacco Digestibility of Wheat Straw

The in sacco digestibility of wheat straw was measured in faunated and defaunated sheep given straw-based diets supplemented with or without lucerne (150 g/day). These studies clearly show that defaunation was associated with an increase in the in sacco digestibility of both treated (ammoniated) and untreated straw (Table 3). The results suggest that the digestive activity of the protozoa which is lost upon defaunation has been more than compensated for by an increase in the digestive capacity of the remaining population of bacteria and fungi. The addition of lucerne (150 g/day) to the diet also stimulated the in sacco digestibility of straw and the effects of lucerne supplementation and defaunation were additive.

Table 3. The in sacco digestibility of wheat straw (WS) and ammoniated wheat straw (NH_3-WS) in faunated and defaunated sheep (Bird et al. 1989).

	In sacco DM digestibility (24-hour incubation) (% DM disappearance)	
Diet	Faunated	Defaunated
WS + urea	26	28
WS + urea + lucerne (150 g/day)	31	33
NH_3-WS	39	43
NH_3-WS + lucerne (150 g/day)	44	50

Productivity of Sheep Given Straw-Based Diets

Defaunation increased wool production and liveweight gain (or reduced liveweight loss) of lambs given diets of wheat straw and various supplements (Table 4). The response in wool growth is clear evidence that the availability of protein for intestinal digestion was enhanced by defaunation since wool growth is highly responsive to increased amino acid absorption (Reis and Schinckle 1961). Intake of wheat straw was increased by defaunation (Table 4), probably as a result of the higher digestibility of wheat straw in the rumen.

Growth Rates of Buffalo Given Straw-Based Diets

Forty-eight Murrah buffalo heifers (average 105 kg liveweight) were allocated to one of eight treatments (4 diets × 2 fauna states). Feed intake and liveweight changes were monitored over a 106-day period. A basal diet of urea ensiled wheat straw, green feed (3 kg/day) and minerals was supplemented with groundnut cake (GNC) at four levels (g/day): 0, 250, 500 and 750. Defaunation increased liveweight gain and improved feed conversion efficiency of heifers on all diets with the response being greatest in animals receiving the GNC supplement (Table 5). Supplementing the basal diet with 750 g/day GNC increased the growth rate of the faunated animals from 220 g/day to 400 g/day (82%), and the growth rate of the defaunated animals from 263 g/day to 477 g/day (82%). A combination of defaunation and 750 g/day GNC increased the growth rate of heifers from 220 g/day to 477 g/day (117%). The response to defaunation may have been greater if all the heifers had remained free of protozoa after the initial treatment.

Table 4. The intake of wheat straw (WS), liveweight change and wool growth of faunated (+P) and defaunated (−P) lambs given straw-based diets.

	Straw DM intake (g/day)		Body-weight change (g/day)		Wool growth (g/day)	
Diet/ref.	+P	−P	+P	−P	+P	−P
1. WS + urea	390	455	−69	−62	1.6	2.3
1. WS + urea + lucerne (150 g/day)	350	520	−20	− 1	2.2	3.2
2. WS + cottonseed meal (80 g/day)	530	575	10	25	3.7	4.7
2. WS + maize (160 g/day)	500	540	24	45	4.1	4.9
2. WS + cottonseed meal (80 g/day) + maize (160 g/day)	460	515	41	59	5.6	6.2

Refs: 1. Bird et al. 1989 2. Habib (1988)

Table 5. Growth rate (g/day) and feed conversion efficiency (FCE) of faunated (+P) and defaunated (−P) buffalo given straw-based diets.

	Total DM intake (kg/day)		Growth rate (g/day)		FCE DMI/gain	
Diet	+P	−P	+P	−P	+P	−P
Basal[a]	3.13	2.57	220	263	18.2	11.1
Basal + GNC[b] (250 g/day)	3.16	3.08	277	370	12.9	9.8
Basal + GNC (500 g/day)	3.50	3.24	360	434	10.1	8.2
Basal + GNC (750 g/day)	3.48	3.14	400	477	9.8	7.3

[a] Basal ration: urea ensiled wheat straw, green feed 3 kg, minerals.
[b] GNC: groundnut cake.

Continual reinfection with protozoa during the study period meant it was necessary to drench each heifer (on average) four times during the 106-day period. During each drenching treatment (2–3 days) feed was not offered and animals took several days to regain full appetite following treatment. Regular drenching therefore greatly reduced feed intake of the heifers.

Results from these studies clearly show that defaunation can improve ruminant production from straw-based diets. Unfortunately there is no satisfactory method currently available for defaunating animals under field conditions. In these studies a detergent (sodim lauryl diethoxy sulfate) drenched directly into the rumen was used to defaunate animals. This method is not suitable for commercial use. The application of this technology is therefore dependent upon the development of a specific protozoal toxin. An alternative approach to chemical drenching may be dietary manipulation. In a recent study conducted at CIRB buffalo heifers were defaunated by a supplement of 350 g/day of leaves (fed for 3 days) collected from a woody shrub. Further research is required in this area.

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Section 5

Draught Animal Production: Reproduction, Breeding and Selection

Nutrient Intake, Workload and Other Factors Affecting Reproduction of Draught Animals

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Abstract

Draught animals play an important role in the agriculture of small farmers. Regular production of calves would further increase the welfare of these farmers. Information has been collected on how nutrient intake, work and other factors may affect reproductive performance of working animals, and in particular, female buffalo and cattle. Normal ovarian activity and normal calving interval are shown to be negatively affected by poor nutrition, management, heat stress and reproductive diseases. Work per se is not a major factor influencing ovarian activity provided energy reserves are adequate. Supplementing feed for thin working buffalo can encourage a return to normal ovarian activity. No supplements are needed when a moderately fat animal is subjected to work. Body condition, level of nutrition, liveweight and work with regard to reproduction are discussed. Genetic factors also contribute to low fertility of both females and males, but more studies are required.

Introduction

DRAUGHT animals have contributed considerably to the rural economy, but little attention has been given to these animals, particularly in terms of their reproductive functions. One of the main recommendations from the first International Workshop on Draught Animals held in Townsville (Copland 1985) was to study the reproduction of draught animals. The other important issue was to make efficient use of locally available feedstuffs.

This paper will discuss current information on reproduction of working animals, mainly buffaloes and cattle, in relation to nutritional status and workload. Other possible important factors affecting reproduction performance are also discussed.

Reproduction

Jellinek and Avenell (1978) found that normal oestrous cycle of swamp buffaloes was 22 ± 1 days and reached a progesterone peak of 2.5 ng/ml by days 12–15. The lowest level was 0.1–0.2 ng/ml. From a review, it is noted that the riverine buffaloes (dairy breed) are younger at first calving and have a shorter calving interval than the draught swamp buffaloes (Momongan 1985). He also noted that 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. A survey 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. Poor nutrition and poor management may be responsible for the high incidence of inactivity of buffalo ovaries. Calving interval of swamp buffaloes varied between 1.7 and 2.9 years (Robinson 1977; Petheram et al. 1982; Bamualim et al. 1987). Robinson (1977) reported that Indonesian buffalo return to service after 2 months postpartum, and require more than two services per conception.

There is some indication that there is little concern or knowledge of farmers about oestrus (Petheram et al. 1982). Silent heat is common in buffalo. True oestrus is detected easily by the bull. Scarcity of

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mature, good-quality bulls may contribute to the slow population growth of buffaloes (Perkins et al. 1986; Toelihere 1988).

Effect of Nutrient Intake on Reproduction

Under village conditions, the growth rate of buffaloes has been reported at 50–230 g/day (Bamualim et al. 1987). Winugroho et al. (1989a) reported that swamp buffaloes which had average body condition score of two, based on Parker and Momongan (1989), had an average liveweight of 285 kg, which would result in cessation of their normal ovarian activity when they were fed only with rice straw for about 77 days. The addition of 1.5 kg of a commercial concentrate Beef Kwik for about 1 month resulted in average liveweight increases from 285 to 295 kg and increased the progesterone level from 0.2 to 1.53 ng/ml. According to Momongan (1985), the cycling buffalo and the pregnant female buffalo always have better body conditions than those which are neither cycling nor pregnant. Buffalo with better body conditions were able to maintain normal ovarian activity although fed only with rice straw for 113 days (Winugroho et al. 1989b). The rice straw had 5.6% CP, 0.8% fat, 3349 kcal/kg, 67% NDF. Beef Kwik had 13.9% CP, 5.9% fat, 4010 kcal/kg and 34% NDF. Jainudeen (1985) stated that if the level of nutrition is such that a lactating cow or buffalo loses body condition during the first 60–90 days postpartum, return to oestrus is likely to be delayed.

More than 40% of nonworking swamp buffaloes were acyclic when feed supplement was supplied to meet a daily gain of 0.2 kg; 6% were acyclic when supplement was given to provide a 0.4 kg daily gain (Putu et al. 1983). The body weight at which ovarian activity commenced was 320 kg for both groups. Loss of approximately 17% of liveweight (56 kg, represented mainly by fat) was detrimental to reproduction function of cattle with medium body condition (Teleni et al. 1988).

Little information is available on the effect of diet on male fertility. Castillo and Lopez (1988) observed that semen quality (density and spermatozoa concentration) of male Holstein decreased significantly when energy concentrate was increased from 40 to 60% in the ration. Similar results were obtained by Castillo et al. (1987).

Interaction between low feeding level and high ambient temperature is likely to have a negative effect on reproduction. Fertility or conception in buffalo cows was reduced at low feeding levels during periods of high ambient temperature (Raizana et al. 1969; Kaur and Arora 1982). Depression of ovarian activity in buffalo cows on submaintenance diet during periods of high ambient temperature was reported by Kaur and Arora (1984).

Effect of Work on Reproductive Performance

Winugroho et al. (1989a) reported that, in general (body condition ranging from very thin to medium-plus) work per se had little effect on the ovarian activity of swamp buffaloes. Average peaks of progesterone levels were 3.0 and 3.1 ng/ml for nonworking and working animals, respectively. Nineteen percent of total cycles in working group animals showed abnormal patterns compared to 12% in the control group animals. The presence of acyclic animals in nonworking groups is also reported by Putu et al. (1983) and Bamualim et al. (1987). It is likely that this was due to poor body condition or low energy feed intake or both. Winugroho et al. (1989b) suggested that a mature working nonpregnant buffalo should have at least 350 kg body weight together with body condition score 3 at the end of any working period in order to maintain normal ovarian activity.

Liveweight loss due to work (draught force about 72 kg, 4 hours work/day) was reported to be greater in heavier working buffalo in better body condition. On average, weight loss was about 0.3 kg/day (range 0.2–0.5) (Winugroho et al. 1988). This implies that the thinner the animal the lower the energy required to complete the same amount of work. Using triated water it was found that, after about 2 months work, total body water of swamp buffaloes was reduced from 67 to 62% of liveweight, and fat content was increased from 10.9 to 14.2% of liveweight, while protein content was constant at 15.3% of liveweight (Winugroho et al. unpublished data). Bamualim and Ffoulkes (1988) concluded that energy body reserves were more economically utilised when working buffaloes were fed with 75% voluntary consumption of a diet consisting of rice straw:field grass (1:1) given ad libitum, and a salt block. However, reproductive capability could be negatively affected when such diet is fed for a long period.

From the information above, the initial liveweight and body condition of the buffalo prior to work can be estimated by assuming that liveweight working cost is 0.3 kg/day and the length of the working period is known.

Additional feed energy during the working period can improve reproduction of animals. Winugroho et al. (1989a) reported that thin mature working swamp buffaloes (average 293 kg) fed with fresh chopped rice straw, with body condition score 2, should require additional nutrients of 1.5 kg concentrate Beef Kwik for approximately 1.5 months to return to their normal ovarian activity. Average liveweight remained unchanged (293 kg). The lack of feed nutrients and energy body reserves could be responsible for the absence of normal ovarian activity in animals. Bamualim et al. (1987) showed that work reduced normal ovarian activity from 75 to 31% of mature swamp buffaloes (average liveweight of 283 kg) fed rice straw:field grass (1:1) ad libitum. The combination of poor body condition and low average liveweight could be responsible for the high incidence of ovarian inactivity.

Other Factors Affecting Reproduction

Good body condition does not always guarantee a good reproduction performance of female (Putu et al. 1983), and possibly male animals (Situmorang, unpublished data). Genetic factors could also be responsible for this trait, but more research is required.

Other factors affecting reproduction of working animals include heat stress, suckling, repeated breeding and reproductive diseases. These have been discussed by Jainudeen (1985). Johnson (1987), in his review, gave data on low progesterone levels during heat stress. Temperature can affect the reproductive process at a number of stages ranging from pubertal development through conception and embryonic mortality. Brahman and Shorthorn cows reached puberty some 5 months later when kept at 26°C compared to those kept at 10°C. Increasing temperature from 18.2 to 33.5°C lengthened the oestrous cycle from 19.5 to 21.4 days, reduced duration of oestrus from 17 to 12.5 hours, increased rectal temperature from 38.3 to 39.6°C, reduced feed intake from 9.4 to 6.2 kg, and increased water intake from 29 to 34.6 l/day (Abilay et al. 1985, cited by Johnson 1987). Capitan and Takkar (1989) reported that a longer number of days was required for follicular development (34 and 29 days), and a shorter first postpartum oestrus (38 and 84 days) when reproductive capacity of Murrah buffaloes was compared in the summer and winter seasons.

Elevated temperatures shortly after mating using artificial insemination will increase body temperature resulting in low fertility from a failure to conceive, or early embryonic mortality. Elevated temperature acts on the testis to impair spermatogenesis (Van Denmark and Free 1970 cited by Johnson 1987), and on the uterus to cause death or damage to the early embryo (Edwards 1978 cited by Johnson 1987).

More physiological data on stressed animals are necessary to understand fully the physiological problems of reduced fertility in hot climates, and the role of reduced LH and progesterone factor in reduced fertility (Johnson 1987). Actual evidence of whether it is the fertilisation process per se or embryonic death (Monty 1984 cited by Johnson 1987) from exposure to high temperature and/or reduced uterine blood flow requires further intensive investigation.

Conclusions

It is concluded that normal ovarian activity can be maintained in working animals if they are fattened before the working season or by giving them a feed supplement during the working season. The first approach is recommended if during the working season farmers are busy with cultivation and do not have enough time to look for green grasses. Preliminary data suggest that at the end of working period the animals should have at least body condition of 6 and liveweight of 350 kg. More studies are needed to define how much energy body reserves should be stored or how much feed nutrients should be given to thin animals.

Research Priorities

Areas for research and development can be suggested towards improved management of working animals by:

(1) Defining minimal nutrient requirements for pregnant and/or lactating working animals without sacrificing their future reproductive performance. In addition, calf nutrition should be studied thoroughly;

(2) Defining minimal nutrient requirements for male working animals;

(3) Developing practical methods to overcome environmental heat stress for working animals, for example through improved feeding management;

(4) Improving local treatments against common diseases and parasites which may potentially reduce reproductive life of working animals.

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Breeding Programs for Improved Draught Animal Power: Crossbreeding of Buffaloes

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Abstract

There is a need to improve the productivity of the Philippine carabao, a swamp-type buffalo (*Bubalus bubalis*), to meet the increasing demand for draught animal power, meat and milk through crossbreeding with the river-type buffaloes. Murrah and Nili-Ravi, which are noted for their large size and good milk production, were selected to be crossed with the Philippine carabao. The breeding plan was so designed as to stabilise the population of crossbreds at 50% indigenous and 50% exotic genes, so that the crossbreds retain their draught power and at the same time produce more meat and milk than the carabao.

The performance of the crossbreds showed that the weights at birth were about 35 ± 1 kg for both Phil-Murrah and Phil-Ravi as compared to 26 ± 1 kg for the Philippine carabao. The weights of the three genotypes at 12 months were: 160 ± 6 kg for the Philippine carabao; 210 ± 9 kg for the Phil-Murrah; and 215 ± 9 kg for the Phil-Ravi. At 2 years of age, the carabao weighed 239 ± 9 kg; Phil-Murrah, 318 ± 17 kg; and Phil-Ravi, 332 ± 19 kg. At 3 years old, the carabao weighed 305 ± 10 kg; Phil-Murrah, 462 ± 24 kg; and Phil-Ravi, 460 ± 25 kg.

Studies on draught ability indicated that F_1 crossbreds are comparable to the Philippine carabao as draught animals in terms of resistance to work stress and docility. There were no significant differences in the PRT of the three genotypes, in response to work stress. Moreover, the draught force of the Philippine carabao and crossbreds at the same body weights were not significantly different.

With regards to milk production, the F_1 crossbreds of swamp- and river-type buffaloes may produce milk daily which is 2.0–2.8 times that which can be produced by the swamp buffaloes.

Introduction

CARABAOS, *Bubalus bubalis*, play an important role in the traditional farming systems in the Philippines. They are raised mainly for draught and secondly for meat and milk. About 99% of the 2.9 million carabaos in the Philippines are in the hands of smallholder farmers. They are generally used to plough, harrow, level land, puddle rice fields and thresh rice; pull carts, sledges, logs, and bamboo poles; extract juice from sugarcane; and serve as riding or pack animals. In some selected areas, caracows are milked for the production of soft cheese and milk-based confectionery. On the average, a carabao is used for 84 working days annually, although in rice-based farming systems, carabaos work for 98 days yearly (Alviar 1986).

About 77% of the farmers in Luzon use carabao power in all their farming activities, while none has a purely mechanised operation. Of those who use machines, 84% of the farmers use machines in only 24% or less of their farm operation. Of the draught

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carabao used by farmers, 63% are males and 37% are females. The carabulls are castrated at a mean age of 3.3 years, with a range of 1.8–4.8 years of age. This practice has resulted in the declining size and weight of the carabao over the years due to negative selection, where small carabulls not selected for draught are the ones mating the female carabaos under village conditions (de Guzman and Perez 1981).

In an effort to improve the size of the Philippine carabao, a breeding program was formulated to cross the carabao with riverine buffaloes. The carabao is expected to contribute to the draught ability, and the riverine buffaloes to the size and milking ability of the crossbred.

Breeding Program

Murrah and Nili-Ravi breeds of buffaloes were selected to be crossed with the Philippine carabao. The selected buffalo breeds are noted for their large size and good milk production. The breeding plan was so designed as to stabilise the population of crossbreds at 50% indigenous and 50% exotic genes, so that the crossbreds retain their draught power and at the same time produce more meat and milk than the carabao (Mahadevan 1981) as shown in Fig. 1. For lack of riverine buffalo bulls in the country, imported semen of Murrah from India and Nili-Ravi from Pakistan was used in the breeding scheme using artificial insemination (AI). Since the carabaos are dispersed in a wide area at the village level, the application of AI is not readily feasible. Thus, oestrus synchronisation is used as a technique for the application of AI in carabaos. Results using this technique gave a conception rate at first service of about 30–35% (Momongan et al. 1984, 1985).

The matings were organised so as to allow the female carabaos to be randomly inseminated with semen from any of the sire breeds (Murrah and Nili-Ravi). Within each sire breed, semen was obtained from a minimum of six bulls maintained at the AI studs of the donor countries. The carabao male × carabao female breeding group serves as the control group.

The F_1 animals were mated inter se within each breeding group to produce F_2 offspring. Thereafter, each crossbred population was stabilised at a 50%

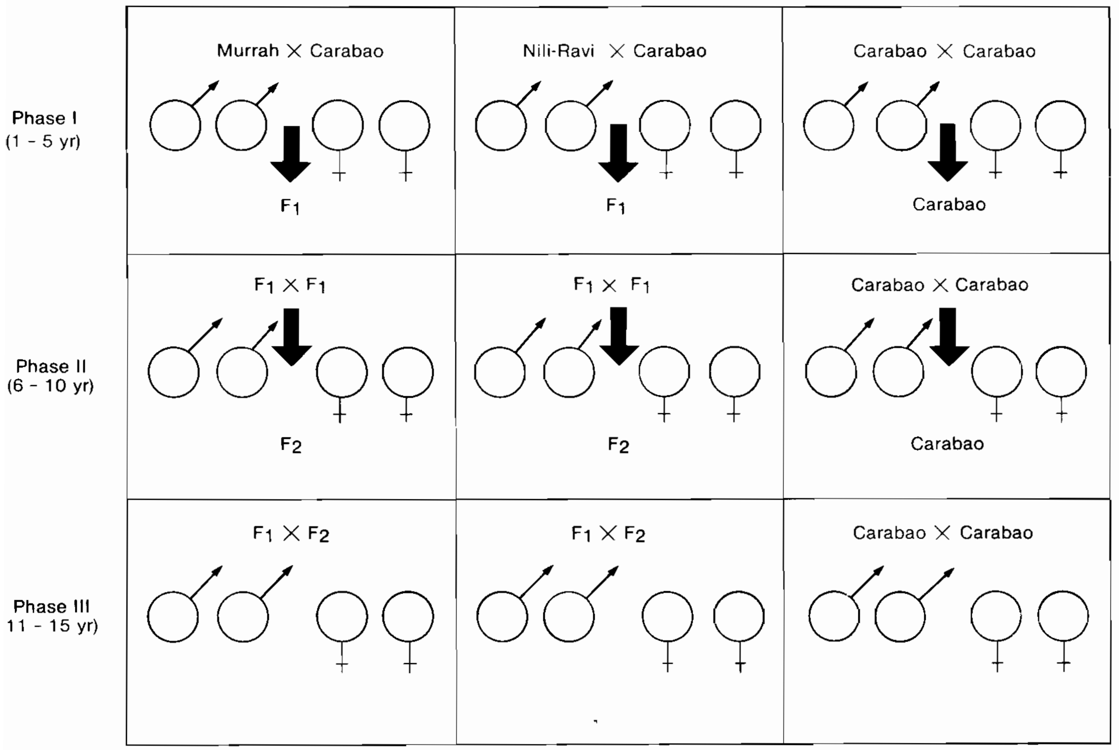

Fig. 1. Design of breeding program for evaluating the genetic potentials of Philippine carabao and its crosses with Murrah and Nili-Ravi under RP/FAO/UNDP — PHI/78/017 — PHI/86/005.

mixture of indigenous and exotic genes by grading to mature progressive F_1 males (Fig. 1).

Growth Performance

Buffalo crossbreds (Philippine Carabao × Murrah or Phil-Murrah and Philippine Carabao × Nili-Ravi or Phil-Ravi) are heavier compared to the Philippine carabaos. Accumulated weight data from 322 carabaos and crossbreds (102 Philippine carabaos, 182 Phil-Murrah crossbreds and 38 Phil-Ravi crossbreds) were statistically analysed using the least square analysis for unequal population (Harvey 1966). The variations in weights among the test animals were primarily due to breeds of sire and locations. Regardless of sex, the crossbreds were heavier than the carabaos at birth, and at 12, 24 and 36 months old (Table 1). Harisah and Azmi (1989) also reported that the least square mean weights of Swamp × Murrah buffaloes were consistently heavier than those of Swamp × Swamp breeding at birth, 6, 12, 18, 24, 36 and 48 months old ($P<0.05$).

Draught Ability

De los Santos and Momongan (1987) conducted two experiments to evaluate the draught ability of the Philippine carabao as compared to Phil-Murrah and Phil-Ravi crossbreds. In experiment I, each buffalo was simultaneously made to carry a pack load equivalent to 20% of its body weight and made to walk a premeasured distance of 6 km. This was repeated 12 times. In experiment II, each buffalo was simultaneously made to pull a sledge with a load equivalent to 50% of its body weight over a fixed distance of 1.6 km. This was repeated 20 times. Results indicated that, in general, the crossbreds are comparable to the Philippine carabaos as draught animals in terms of resistance to work stress and docility (Tables 2–5). There were no significant differences among the three genotypes in the initial and final pulse rates, respiration rates and body temperatures (PRT). As expected, the load stress increased the PRT significantly ($P<0.01$) after work within breeds. However, among genotypes, the differences were not significant indicating that all the three genotypes react similarly to work stress.

Garillo et al. (1987) compared the ploughing ability of the Philippine carabao and Phil-Murrah crossbred steers. Four mature Philippine carabaos and four Phil-Murrah crossbred steers (weighing about 520 kg and 4–7 years old) were evaluated for draught power to plough under wet and dry land conditions. PRT changes before, during and after the ploughing were recorded. There were no significant differences ($P>0.05$) in the ploughing ability between the Philippine carabao and Phil-

Table 1. Least-square means (LSM) and standard error (SE) for body weights of Philippine carabao, Phil-Murrah F_1 and Phil-Ravi F_1.

Age (months)	Philippine carabao		Phil-Murrah F_1		Phil-Ravi F_1	
	n	LSM ± SE (kg)	n	LSM ± SE (kg)	n	LSM ± SE (kg)
0	102	26 ± 1^a	182	35 ± 1^b	38	35 ± 1^b
6	95	111 ± 5^a	172	127 ± 6^b	37	133 ± 6^b
12	85	160 ± 6^a	160	210 ± 9^b	31	215 ± 9^b
18	75	204 ± 7^a	125	281 ± 15^b	27	283 ± 11^b
24	58	239 ± 9^a	105	318 ± 17^b	24	332 ± 19^b
36	48	305 ± 10^a	98	462 ± 24^b	21	460 ± 25^b

Average least square means with different superscripts in the rows differed significantly ($P<0.01$) from each other.

Table 2. Effect of pack-loading on average pulse, respiration and temperature of buffaloes without wallow.

Breed	Pulse (counts/min)		Respiration (counts/min)		Temperature (°C)	
	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]
Phil-Car	39.4	57.4	23.4	56.3	38.0	40.1
Phil-Mur	38.1	57.6	22.4	61.6	38.1	39.5
Phil-Rav	38.5	61.1	21.8	57.2	38.0	39.9

n = 4 draught animals for each genotype with 12 replications.
Phil-Car — Philippine Carabao.
Phil-Mur — Philippine Carabao-Murrah F_1.
Phil-Rav — Philippine Carabao-Nili Ravi F_1.
ns — not significant ($P>0.05$).

Table 3. Effect of pack-loading on average pulse, respiration and temperature of buffaloes provided with wallow.

Breed	Pulse (counts/min)		Respiration (counts/min)		Temperature (°C)	
	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]
Phil-Car	36.6	58.6	16.6	58.4	37.8	39.5
Phil-Mur	40.2	58.1	18.9	54.8	37.9	39.2
Phil-Rav	40.4	59.9	16.9	65.2	37.7	39.5

n = 4 draught animals for each genotype with 12 replications.
ns — not significant ($P > 0.05$).

Table 4. Effect of pulling sledge stress on physiological responses of buffaloes without wallow.

Breed	Pulse (counts/min)		Respiration (counts/min)		Temperature (°C)	
	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]
Phil-Car	40.1	69.8	23.1	82.8	38.1	40.9
Phil-Mur	38.7	68.9	23.8	86.5	38.2	40.6
Phil-Rav	40.0	73.0	21.0	89.7	38.0	41.0

n = 4 draught animals for each genotype with 20 replications.
ns — not significant ($P > 0.05$).

Table 5. Effect of pulling sledge stress on physiological responses of buffaloes with wallow.

Breed	Pulse (counts/min)		Respiration (counts/min)		Temperature (°C)	
	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]	Initial[ns]	Final[ns]
Phil-Car	38.1	68.4	17.5	81.3	37.9	40.3
Phil-Mur	42.5	66.1	18.8	79.1	37.7	40.1
Phil-Rav	41.2	69.3	19.0	86.0	37.9	40.6

n = 4 draught animals for each genotype with 20 replications.
ns — not significant ($P > 0.05$).

Table 6. Work performance of Philippine carabao (PC) and crossbred (F_1) Phil-Murrah steers (CB).

Parameters	Wet land condition		Dry land condition	
	PC	CB	PC	CB
Depth of ploughing (cm)	12.25 ± 0.5	12.23 ± 0.6	11.92 ± 0.6	11.14 ± 0.7
Width of ploughing (cm)	17.61 ± 1.0	17.69 ± 0.9	18.94 ± 1.1	18.57 ± 0.8
Soil moisture (%)	42.96 ± 2.0	43.74 ± 1.9	22.92 ± 2.1	22.55 ± 1.9
Hardness of soil (kg/cm^2)	1.66 ± 0.4	1.66 ± 0.3	1.91 ± 0.4	1.92 ± 0.1
Ploughing velocity (m/sec)	0.50 ± 0.1	0.54 ± 0.2	0.60 ± 0.1	0.50 ± 0.1
Ploughing time (hours) for 2500 m^2 area	8.89 ± 0.8	8.29 ± 0.7	7.14 ± 0.8	8.72 ± 0.7
Average draught force (kg)	54.14 ± 2.3	49.24 ± 2.1	50.14 ± 2.3	50.60 ± 2.1
Drawbar horsepower (PS)	0.36 ± 0.1	0.35 ± 0.1	0.40 ± 0.1	0.34 ± 0.1

Source: Garillo et al. (1987).

Table 7. Average milk yield of Philippine carabao, Phil-Murrah F_1 and Murrah buffaloes in 300 days lactation period.

Parameters	Philippine carabao	Phil-Murrah F_1	Murrah
Lactation yield (kg)	451 (17)*	1242 (9)	1310 (8)
Daily yield (kg)	1.50[a]	4.14[b]	4.37[b]

* The figure in parentheses indicates the number of lactation samples. Figures with the same superscript are not significantly different from each other at 5% probability level.

Murrah crossbred (Table 6) in terms of depth, width and velocity of ploughing, as well as draught force and drawbar horsepower. Moreover, there were no differences on the PRT measurements of the Philippine carabao and Phil-Murrah crossbreds as influenced by ploughing either under wet or dry land conditions (Garillo et al. 1987). This indicates that the crossbreds are as adaptable to work as the Philippine carabaos at the same body weights.

Milk Production

The milk production of Phil-Murrah F_1 is about 2.8 times that produced by the Philippine carabao (Table 7). There are insufficient data on the milk production of Phil-Ravi crossbreeds to warrant statistical analysis. However, Xiao (1989) reported that the average daily milk yield of swamp buffaloes was 1.94 kg in 10 lactation records; the F_1 of Swamp × Murrah, 3.73 kg in 12 lactation records; the F_1 of Swamp × Nili-Ravi, 4.3 kg in 60 lactation records; the purebred Murrah, 6.60 kg in 81 lactation records; and the purebred Nili-Ravi, 7.2 kg in 25 lactation records. The average length of lactation was 235.9 days for swamp buffaloes; 276.9 days for Swamp-Murrah F_1; 270.8 days for Swamp-Ravi F_1; 237.1 days for purebred Murrah and 261.0 days for purebred Nili-Ravi.

Again, the data show that the F_1 crossbreds of swamp and riverine buffaloes may produce twice as much milk daily as that produced by swamp buffaloes. Thus, it may be inferred that the F_1 crossbred of swamp and river buffaloes may produce 2.0–2.8 times more milk daily than swamp buffaloes.

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Genetic Improvement of Draught Animals

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Abstract

In considering the need for genetic improvement of draught animals it is necessary to recognise the multipurpose role of animals in existing systems, and the changes in the relative importance of these various roles that are likely to occur in the next 20–25 years. Given the increase in mechanisation in some areas and the decrease in farm size that is occurring in others, and coupling this with a general increase in demand for meat and milk throughout much of the Asian region, the use of animals for draught is likely to decrease relative to their use for other purposes. Genetic improvement should be directed primarily towards increasing growth rate and fertility on modest fibrous rations, both of which will have direct benefits to draught power. Culling procedures should recognise the importance of physical defects and attributes of animals in performing work. Genetic improvement in small farmer systems is only feasible using crossbreeding; the basic requirements for within-breed selection are not available nor are they likely to become available. This implies a need for breed evaluation research on a strictly comparative basis of indigenous breeds and their crosses and the possible role of introduced breeds.

Introduction

DRAUGHT animal power (DAP) is still a major source of energy input into smallholder systems in Asia and Africa. However, for a variety of reasons, this use of animals in some systems is declining, at least in Asia.

On the one hand, farm size is declining to a point where animals are being eliminated from the system (e.g. Bangladesh), and on the other, traditional tasks using draught animals are rapidly being replaced by small tractors (e.g. Thailand, Philippines, Malaysia, Korea, China). In Indonesia both factors are operating; farm size is gradually decreasing and in some areas, notably the northern plains of West Java where rice production has been intensified, small tractors are prevalent.

Draught power is only one of several animal inputs into small farmer systems that contribute to the generation of income. It has been estimated that an increase of 1 hour of DAP will produce an additional 10 kg of rice in West Java (Esparon and Sturgess 1989). Other inputs include manure and milk and, at the end of the animal's working life, meat, with hides and horns a minor source of income.

Thus in considering the need for draught animal improvement, and the manner in which it may be achieved genetically, the following factors need to be considered:

(1) the time scale needed for genetic change whether by selection or crossbreeding;
(2) an assessment of the relative importance of draught animals 20–25 years from now;
(3) whether the prime need is for greater numbers of animals with submaximal draught power capacity or for greater capacity in the existing or expanded numbers;
(4) whether genetic improvement for other characteristics (e.g. milk and meat) should receive priority; and
(5) feasibility of genetic improvement within small farm systems and acceptance of such technology and products by the smallholder.

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Time Frame of Genetic Change

Relative to other technologies, genetic improvement is slow, although gains are permanent and may be relatively cheap. This is particularly true for mass selection techniques but also holds for crossbreeding technologies.

Mass selection procedures require a large and relatively sophisticated infrastructure to be successful (Starkey 1985), conditions that impose severe constraints on the implementation of such schemes in many developing countries, and the rate of genetic improvement is therefore considerably slower than in ideal situations.

Crossbreeding, although potentially more rapid (improvements in one generation are possible that may take 20–30 by selection), also has disadvantages related to the supply and distribution of appropriate genotypes for crossbreeding programs. Whilst AI is the most desirable form of distribution this too requires a considerable infrastructure.

For example, the introduction of Brahman cattle into the British breed herds of northern Australia took approximately 30 years from the time that research results demonstrated their value. This is a penetration rate of 7%/year. It should also be remembered that the producers in this instance were well educated and profit-motivated.

With crossbreeding there is also the residual problem of where to go from the F_1 crossbred — a problem that has largely been unsolved. One option is to develop new synthetic or derived breeds through inter se mating of the F_1 generation followed by selection within the F_2 and subsequent generations. Whilst there is some evidence in cattle in some situations that performance will not decline from the F_1 to subsequent generations (Dillard et al. 1980; Gregory and Cundiff 1980; Robison et al. 1981) experimental data on cattle and buffalo in smallholder systems are lacking. On theoretical grounds Frisch (1989) has argued that the extent of the decline from F_1 to F_2 depends on the relative production potential of the parental breeds and the environment in which the crossbred is used.

Thus, in considering prospects for a significant impact of genetic improvement through either selection or crossbreeding, a time frame of 25 years must be considered conservative. In many situations it may be 50 years or more.

Future Importance of DAP

It is difficult to predict the importance of DAP in small systems 20–30 years from now. Quite apart from the prediction of the availability and price of fossil fuels for mechanical farming methods, there are considerations of population pressures and, associated with this, farm size.

Mechanisation is increasing in countries such as China, Indonesia, Philippines, Malaysia, Korea and Thailand. The situation in Burma, Laos, Vietnam and Kampuchea is unclear. In countries like Bangladesh, and probably most African countries, mechanisation is rare, and yet DAP is static or declining because of decreasing farm size and the inability of small farms to support a large ruminant.

Rather than trying to investigate these unknowns, and relying on inaccurate and possibly incorrect predictions on the future importance of DAP, it is more reasonable to argue that there will be a continuing and increasing role for animals and their products in the developing countries. Although milk and meat may increase in importance relative to draught, animals will continue to fulfil a variety of roles. As long as improvements in these characters can be achieved without reducing draught capacity, then genetic improvements to overall productivity should be pursued without necessarily giving special reference to draught.

Ways of Improving Draught Output

Ways of improving draught output have been presented previously (Vercoe et al. 1985). One question that concerns us here is whether it is the quantity or quality of draught power that is deficient. Quantity is a function of numbers to which reproductive capacity is the key, whereas quality is a function of the physiology and anatomy of existing animals and the availability of implements and harness.

Increasing numbers are associated with an increase in feed supply, a limiting resource in many situations at the present time. However, in some circumstances a small farmer may prefer to have two smaller animals in place of one larger animal because they can perform the work required and financial risk is spread. Increasing the supply of available feed is a separate issue that relates to maximising the use of agricultural by-products (rice straw, rice bran, etc.), a problem that is being actively studied by many institutions in southeast Asia including those in Indonesia (Gunawan 1988).

Quality of draught power implies a need to improve the output per head of existing animals. Despite the fact that DAP is required for only 60–120 days/year, these days are critical in terms of overall productivity of the smallholder systems. In most cases the time taken to cultivate the required area will not be significantly reduced by improving draught capacity, i.e. an increase in speed of working is not a prime requirement. What is important is to increase the number of hours worked per day so that land preparation and cultivation can be achieved at optimal times and to ensure that the land preparation is maximal (i.e. depth of ploughing, weed control, etc., are such as to maximise crop yield). The major determinants of these requirements are power output, which is proportional to size and weight, and temperature regulation.

Many indigenous buffalo and cattle do not reach their genetic potential for weight per age nor are they at peak weight and condition at the beginning of the working season. Both of these factors are a function of the quantity and quality of the available nutrition.

However, there is also genetic variation between and within breeds for weight for age and size, and utilisation of this variation in breeding programs will have direct economic benefits in meat-producing enterprises which will have spin-off benefits to DAP.

Improving the temperature regulation of buffalo through genetic means specifically to improve draught capacity is a long-term process. It is unnecessary in relation to improving milk and meat production because the provision of wallows and other management practices overcomes the depression in productivity associated with increases in rectal temperature. Although genetic variation within and between breeds of buffalo should be assessed and utilised when it exists, there seems little point in expending research effort in selecting for heat tolerance. However, ways of reducing the heat load on working buffalo should be investigated (e.g. shading, damp muslin cloths to produce evaporative cooling — Chikamune and Shimizu 1985).

Physical defects, particularly those relating to leg structure, hoof size and shape, shape and size of horns, may be important in the draught animal but of lesser or no importance to meat and milk production. However, as long as there is a demand for draught animals, those features important for draught, whether they be directly related to power output or related to ease of harnessing and harness design, should be incorporated into any culling or selection or crossbreeding policies.

Priorities for Genetic Improvement

Given the possible changes relating to the herds and contributions of animals in small farm production systems over the next 25–30 years, it would be prudent to concentrate efforts for genetic improvement on increasing meat and milk production. These efforts, however, should be tempered by the knowledge that these animals may also be required for draught in some circumstances. In any event genetic gains in such characters as weight for age and fertility will have direct benefits to draught power output, through either the quality or quantity of draught power available. In so far as heat tolerance is important for efficient meat and milk production, gains in this trait will also benefit draught output.

However, diluting potential genetic gain in these characteristics by adding other characters that are of perhaps marginal significance in increasing draught power output is undesirable.

Research effort would be more effectively spent in other areas of potential benefit to draught output, e.g. maximising weight and condition at the commencement of the ploughing season by nutritional means, management modifications to reduce heat stress (shade, wet cloths) and improving implements and harness.

Prospects for Genetic Improvement

Genetic improvement arising from within breed selection and progeny testing of superior genotypes is a daunting task in smallholder systems. It requires some central or series of breeding stations where effective selection can take place, and with sophisticated data collection and processing systems. In addition, the technology for dispersing the superior genetic material throughout the villages and feedback on the performance of progeny has to be considered. Large-scale AI of village buffaloes has been moderately successful in Thailand (Kamonpatana, pers. comm.) and the Philippines (Momongan, pers. comm.), but assessing the relative merits of sire progeny groups in the villages presents a major constraint.

When it is realised that in highly developed production systems the genetic gains from within-breed selection are of the order of 1–2%/year, a rate of gain below the population increase in many developing countries, the enormity of the task in both size and resource requirements becomes clear (Frisch and Vercoe 1984).

On the other hand, utilising the between-breed and strain differences in large ruminants in crossbreeding programs, whilst still a long-term and large task, nevertheless is likely to produce increases in productivity more in keeping with the needs and aspirations of small farmers.

This task also requires considerable input of resources to obtain good comparative data on the relevant differences between breeds and strains of cattle and buffalo. It requires good dissemination systems to release appropriate genotypes to villages. However, much of this technology is available but requires refinement and organisational skills to implement. Synchronisation and AI in large-scale projects could have significant impact in a relatively short time, provided that the basic evaluation data are available. ACIAR is supporting the collection and analysis of such comparative data in buffalo genotypes in Asia.

Conclusions

In common with other authors (Frisch and Vercoe 1984; Chantalakana 1985; Starkey 1985) we suggest that there is little to be gained from having genetic improvement programs specifically aimed at improving draught animal power.

Draught output should capitalise on genetic gains made in growth and fertility, areas in which the major efforts for genetic improvement should be placed in anticipation of the increasing demand and profitability in meat and milk production. Genetic improvement should be undertaken recognising that increases in production must be forthcoming from feeds of very modest nutritive value.

Genetic gains will accrue most rapidly and in a realistic time frame from crossbreeding rather than from within-breed selection.

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Genetic Differences Among Asian Swamp Buffalo Populations

J.S.F. Barker*

Abstract

Increasing the value of economically important domestic animals, such as the swamp buffalo for draught power, may be achieved by changing the animals by genetic means or by changing the environment of the animals. Here possibilities for genetic change are considered, but it is emphasised that no one approach should be considered in isolation, and that the total integrated production system should be manipulated to maximise gain in value.

Possible methods of genetic improvement, and the constraints on each, are discussed. As the vast majority of swamp buffalo are owned by small farmers, large-scale selection programs are not a viable option, and most attention has been devoted to crossbreeding of swamp buffalo with the river buffalo. F_1 crossbred animals are likely to be generally superior to pure swamp buffalo, but there is no clear way to proceed from the F_1. A third approach, which could be used if there were genetic differences among swamp buffalo populations, involves crossbreeding between swamp buffalo populations or grading up to the best population.

An ACIAR-supported research program is investigating genetic differences among swamp buffalo populations, using loci coding for proteins and enzymes expressed in blood. The nature of this project is described and some preliminary results presented. These indicate that there may well be substantial genetic differences among swamp buffalo populations.

Introduction

THE primary aim of animal science research is to increase the value of economically important domestic animals for fibre, meat, milk, draught and various other production characters and/or for social reasons. Increasing value for one or more purposes implies an economic assessment, whereby the benefits of any imposed manipulations must be considered relative to the costs involved. The manipulations that might be imposed are many and varied, but in essence may be categorised into:

(1) changing the animals by genetic means, or
(2) changing the environment of the animals, where environment is defined in the broadest sense to include not only feeding, management systems and incidence of diseases and parasites, but also socioeconomic, political and cultural factors.

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Here I will consider the possibilities for, and implications of, genetic change. However, it must be emphasised that no possible manipulation should be considered in isolation. There is no one best approach to increasing value, and changing any one component that affects value will be likely to change others. Animal production is an integrated activity, so that the total system must be defined and evaluated in any attempt to improve productivity. Further, productivity is not just productivity per surviving animal, but also includes survival and reproduction rates, which are determined largely by adaptation to the environment (Barker 1985a).

Methods for Genetic Improvement

The application of genetics to improving productivity entails either:

(1) utilisation of differences among breeds/strains through crossbreeding, grading-up to the superior breed/strain, or formation of a synthetic population, or

(2) utilisation of within-breed/strain variation through selection.

Again, these are not discrete alternatives. For example, (a) breeds/strains being used for crossbreeding should be under selection for continued improvement of those characters that have high heritabilities and show little or no heterosis, and (b) an identified superior breed/strain should be under selection for further improvement.

Genetic Improvement of Swamp Buffaloes

In theory, these methods could be applied for the genetic improvement of swamp buffalo for draught or meat production, but in practice, these are severe constraints on their application.

In the developed world, most livestock improvement programs depend on a substantial industry infrastructure, and on animal identification, recording schemes and often sophisticated statistical techniques for the estimation of breeding values of individual animals. For swamp buffaloes, the infrastructure for such programs does not exist, economic realities preclude its development, and there are further constraints imposed by the population structure, with only one or two animals owned by a majority of farmers. Smith (1988) has proposed that these constraints and difficulties could be overcome by the development of nucleus breeding units, and I would argue that this technology for genetic improvement should be seriously evaluated for the swamp buffalo.

Nevertheless, selection programs are not an immediately viable option and most attention has been given to crossbreeding, particularly to crossing of the swamp and river types to improve the performance from heterosis in the F_1 crossbreeds. The F_1 animals are likely to be generally superior to the swamp type in growth rate and possibly in draught performance. However, this approach is not without potential problems. It is well known that the river and swamp buffalo differ in chromosome numbers; $2n = 50$ and 48 respectively. F_1 animals have 49 chromosomes, and if the F_1 are mated inter se, all three chromosome constitutions segregate in the F_2. What is not clear is whether $2n = 49$ animals suffer any decrease in reproductive capacity, nor what the best breeding program should be from the F_1. Further, this breeding program may depend on defining the chromosome constitution of individual animals, which would likely be a severe constraint on its successful implementation.

The remaining option for genetic improvement of swamp buffaloes has been given scant consideration, because it depends on there being genetic differences among swamp buffalo populations, and there are absolutely no available data.

If there were genetic differences among populations (i.e. from different countries or even different geographical regions within a country), these differences could be utilised in two ways:

(1) crossing between populations, where expected heterosis is proportional to the magnitude of genetic difference between the populations, or

(2) grading-up to the best population.

The possible application of this option depends on knowing if there are genetic differences among populations, and if there are, identifying the population(s) that are superior for the trait(s) of interest — draught power, meat production, etc. Identification of superior population(s) depends on appropriate evaluation of all populations, i.e. comparison under the same conditions, of contemporary animals from the different populations, with collection of objective data on them (Barker 1980). Given the large number of geographically separate populations of swamp buffalo, it obviously will not be possible to evaluate all of them.

I have previously argued (Barker 1980,1985b) that the solution to this dilemma is to determine the genetic relationships among the populations, so that they may be grouped into sets that are genetically similar, and then to include in evaluation programs one representative population from each set. ACIAR Project 8364 (Genetic Identification of Strains and Genotypes of Buffaloes and Goats in Southeast Asia) has been designed to provide data on the genetic relationships among a sample of swamp buffalo populations.

Estimation of Genetic Relationships

The methodology, which derives from studies in evolutionary genetics, has been presented by Barker (1985a). In brief, biochemical genetic methods are used to determine the genotypes of individual animals at loci specifying various proteins, usually enzymes, using the technique of electrophoresis. The loci analysed most likely will have no (or little) effect on production traits of interest; the point is to determine if populations are genetically different for what is hoped will represent a random sample of the genome. For the estimated relationships to be as

Table 1. NADH-diaphorase (zone 3) phenotype and allele frequencies for three swamp buffalo populations.

Population		Phenotypes			Alleles	
		100/100	100/104	104/104	100	104
Malaysia	obs	15	21	14	0.51	0.49
	exp	13.0	25.0	12.0		
Philippines	obs	23	20	7	0.66	0.34
	exp	21.8	22.4	5.8		
Indonesia	obs	15	24	11	0.54	0.46
	exp	14.6	24.8	10.6		

Table 2. Carbonic anhydrase phenotype and allele frequencies for three swamp buffalo populations.

Population		Phenotypes			Alleles	
		100/100	100/95	95/95	100	95
Malaysia	obs	36	14	0	0.86	0.14
	exp	37.0	12.0	1.0		
Philippines	obs	31	19	0	0.81	0.19
	exp	32.8	15.4	1.8		
Indonesia	obs	0	6	44	0.06	0.94
	exp	0.2	5.6	44.2		

reliable as possible, it is essential that a large number of loci be analysed. In this study, we are aiming to assay at least 70 loci in this first phase, but it must be noted that about two-thirds of these are expected to show no variation, and so will be uninformative. Our genetic relationship estimates therefore will be based on about 20–25 loci.

When the genotypes at a particular locus are determined for all individuals sampled from each population, the gene frequencies at that locus in each population can be estimated. The estimated genetic relationships among any two populations are a function of differences between them in gene frequencies. For example, if the two populations are homozygous for different alleles at a particular locus, the relationship estimated from that locus is zero, while if the gene frequencies in the two populations are identical, the relationship is unity. As noted above, more accurate relationships are obtained by averaging over many loci.

The development of the assay techniques is being done mainly in my laboratory at the University of New England, and assay of the population samples in the laboratory of Professor T.K. Mukherjee, University of Malaysia, supervised by Professor Mukherjee and Dr S.G. Tan, Universiti Pertanian Malaysia. In Project 8364, we plan to collect blood samples from 50 animals in each of 14 populations — from Indonesia, Malaysia, Philippines, Sri Lanka, Thailand and Australia. Details of the completed assay systems and initial results for five polymorphic systems in three populations have been presented by Tan et al. (1989) and by Selvaraj et al. (1989).

At this stage, assay systems have been developed for 40 enzymes, most of which had not previously been studied in buffaloes. A further 22 enzymes or proteins have been detected by our assay system, but the optimum assay method has not yet been determined.

Some Preliminary Results

In the population samples from Malaysia, Philippines (Mindanao) and Indonesia (Medan, Sumatra), 27 loci have so far been studied (some for only small numbers of animals), and 11 were found to be polymorphic. To illustrate the type of data being obtained, results will be discussed for two polymorphic systems, viz., NADH-diaphorase (zone 3) and carbonic anhydrase, where all 50 animals sampled from each of the three populations have been assayed (Tables 1 and 2).

For NADH-diaphorase (zone 3), three phenotypes were observed on the electrophoresis strips, and family studies were consistent with these being the products of two codominant alleles at this locus. Within each of the three populations, the observed frequencies (Table 1) do not differ from expected Hardy–Weinberg equilibrium frequencies, i.e. each population is in equilibrium under random mating as far as this locus is concerned. Further, the phenotype and allele frequencies in the three populations are quite similar, and are not significantly different among the populations (phenotype frequencies), $\chi^2(4) = 5.128$, $P = 0.274$; allele frequencies, $\chi^2(2) = 5.141$, $P = 0.0777$.

For carbonic anhydrase (Table 2), there were also three observed phenotypes and family data again were consistent with two codominant alleles determining these phenotypes. Again observed and expected frequencies for each population are not significantly different, but for this locus, there are highly significant differences among the populations. The Malaysian and Philippine populations are very similar, with a high frequency of allele CA^{100}, but the Indonesian population is very different, with a high frequency of allele CA^{95}.

Obviously these data represent a very small subset of the total results that will be obtained, but they do serve to indicate that there may well be substantial genetic differences *among* swamp buffalo populations that could provide the basis for rational evaluation studies and for genetic improvement programs.

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Selection of Animals for Work in Sub-Saharan Africa: Research at the ICRISAT Sahelian Centre

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Abstract

Increasing the availability of power per hectare by using draught animals can increase crop yields and cropping areas by reducing the time necessary to perform certain agricultural tasks and by improving soil tillage.

In Niger 73% of the animals available are cattle, but the total number is too low to provide every household with draught animals. Therefore all species must be evaluated on characteristics like costs, temperament and draught performance.

A literature review is included, as well as results on draught capacity trials with sledges and a braking device. Average and maximum power and work outputs for all species were determined in relation to the imposed draught forces and animal liveweights.

Up to forces of 528 N, pairs of bullocks showed highest work outputs, followed by camels, horses and single bullocks respectively. Above forces of 540 N, pairs of bullocks showed the highest work output, followed by single oxen, horses and camels. Single bullocks and camels cannot pull above 900 N. Horses cannot pull above 1100 N, leaving only pairs of bullocks capable at that level.

For horses, work optima range between 5.46 and 10.47 MJ and are reached at 548–670 N; for single bullocks 5.14–8.23 MJ was reached at 439–658 N; and for camels, 6.09 MJ was reached at 438 N.

Power output is reached at higher forces than work output. Horses reached maximum power outputs between 1074 and 1302 nm/sec at forces between 889 and 1133 N. Single bullocks reached maximum power of 654–1021 nm/sec at 548–883 N. For camels power outputs of 425–1338 nm/sec were reached at forces of 332–883 N.

Pulling forces, power and work outputs increased with increasing animal liveweights. The power and work outputs per kilogram liveweight, on the contrary, decrease. Increases in force lead to decreases in speed, but to increases in power output.

Very high forces can only be generated for short periods of time. With the braking device, peak performances were measured. Equines appeared to generate absolutely and relatively much higher instantaneous forces (103–115% × liveweight) than bovines (30% × liveweight). Therefore equines are more suitable to work on fields that have not been properly cleared.

A pair of bullocks of equal liveweight can generate less than twice the power of the same oxen working as singles. The difference is not constant as is suggested in the literature but depends on the force required. Working with two singles leads to a higher work output in hectares/day of up to 55%, but costs 10–20% more time per hectare than working with them as a pair.

As most species are not strong enough to perform agricultural tasks that require 900 N or more, pairs of horses and camels should also be tested. As cows can produce several products, including milk and draught, maintenance feed is more efficiently used by cows than by bullocks. When farmers can only afford one or two animals cows may be a sound alternative. Therefore cows should also be tested.

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Introduction

ANALYSES of statistics revealed a correlation between available power per hectare and crop yield. A high rate of increase of yield for increasing power inputs up to a level of about 0.4 kW/ha was found. In Africa, one adult person provides 0.1 kW/ha, thus with a supplementation of 0.3 kW/ha, yields would increase considerably. A pair of work oxen would provide such supplementation for about 3-4 ha of land, a 50 kW tractor for 150–200 ha.

The failure of many capital-intensive mechanisation schemes and their dependency on foreign exchange has created renewed interest in draught animal power (DAP). A pair of work animals per household proved to be more feasible than shared ownership of tractors. Thus oxen seem a reasonable solution for smallholders (Giles 1975).

Development of DAP in Sub-Saharan Africa

Except for Ethiopia all sub-Saharan countries have no tradition using DAP systems. In West Africa cattle belong to nomads while land is owned by the sedentary cultivator. In most countries where draught animals are now used, the practice was introduced in this century and in the context of cash crop production.

In sub-Saharan Africa about 10 million draught animals were in regular use in 1981, of which 50% were in Ethiopia. Draught animals cultivated about 15% of the land sown with annual crops (ILCA 1981).

In the Sahel in 1981 there were about 1.3 million draught animals, or 13% of the total. About 14% of the land sown with annual crops was cultivated using DAP. Draught animals supplied 6% of the power input in agriculture while tractors supplied only 1%. The main source of power in agriculture in the Sahel is still people, who are responsible for 93% (ILCA 1981).

There are regional differences in the use of draught animals, partly based on the crops cultivated in the area. So far, draught animals are mainly used for cultivation and seeding. For groundnuts, DAP is used for harvesting. Weeding is of lesser importance at present, but it may increase in importance in the future.

De Montgolfier-Kouevi and Vlavonou (1981) estimated that the potential contribution of animal traction to the power requirements of agriculture in the Sahel in the year 2000 would be 20% of the total.

Table 1. Numbers of animals per species and per 1000 inhabitants in Niger 1986 (FAO Yearbook 1987).

Species	No. (000s)	Percentage of species	No./1000 inhabitants
Cattle	3300	73.1	796
Horses	292	6.5	70
Asses	507	11.2	122
Camels	415	9.2	100

Their estimation was based on the assumption that animal numbers would be 20% of the cattle herd as projected for 2000 and that animal performance would improve 20% in the Sahel (ILCA 1981).

Animal Supplies

In West Africa, farmers must purchase their animals from the nomads. Thus introduction of DAP technology in this area has to be accompanied by a credit system. Farmers must also learn how to handle and care for their draught animals. An advantage of the relative absence of livestock in the system is that crop residues and forage of pasture and fallow land can be used to feed draught animals. Equines are present in low numbers in the Sahelian countries, and are mostly used for riding and transport.

In Niger the policymakers have decided in favour of the use of working animals, thus stimulating research into the possibilities of introducing DAP systems.

FAO estimated that in 1986 the human population of Niger was 4.1 million, with an average of one draught animal per person (Table 1). Not all animals are mature and ownership is certainly not equally divided among the population but most households can be provided with DAP when all animal species are used (FAO 1987). Species availability will determine the animals to be used in given areas of the country.

Although 73% of the draught animals in Niger are bovines, camels are the dominant species in the north.

On light sandy soils the use of donkeys and single horses can be quite satisfactory. On heavy clay soils cattle, horses and camels, mostly in pairs, are necessary to provide the required power.

DAP Effects on Agricultural Production

DAP is reported to have five main effects on agricultural production (Anderson 1985). Firstly, DAP is labour saving compared with hoe cultivation. This generally leads to expansion of the area sown with crops.

Secondly, labour saving can result in earlier planting which has a beneficial effect on crop yield as the crops can use more of the rain water. In Niger, on the contrary, ridging appeared to increase time needed for planting which can be a disadvantage in seasons with low rainfall.

Thirdly, labour saving is most significant in weeding. Ridging with DAP resulted in less weed growth than clearance by hand. Therefore the first weeding with DAP took only 7% of the weeding time needed by hand weeding. Weeding with DAP was not only faster but also suppressed regrowth of weeds. The final result of better and faster weeding was higher crop yield because the plants experienced less competition for water and nutrients.

The fourth, and disputed, effect of DAP systems is an increase in yield/hectare. At the research station in Niger, several experiments proved that ridging resulted in better emergence, establishment and growth of both millet and cowpea plants. The effects of tillage were based on decreasing wind erosion and water runoff, but also on the relative absence of weeds during early crop growth. On fertilised plots the effect of tillage was even more significant, probably due to the concentration of fertiliser around the roots by ridging. The effect of tillage depended largely on the cultivars used. Introduction of DAP tillage in Niger seemed to be of little use when not accompanied by introduction of fertiliser and improved varieties of millet and cowpea.

The fifth effect of DAP systems is on cropping pattern. Experiments in Niger did not indicate that the traditional cultivation of millet, with the cowpea sown 3 weeks later as intercrop, should be abolished. However, sowing on lines at regular spacing was required when ridging was practiced. Generally DAP users tend to increase the cultivation of cash crops (cowpea) because they have to repay the loans for the purchase of animals and implements (Broeckhuyse 1983).

Research in Niger

From May to November 1987, research on animal traction was done at the research station of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niamey, Niger. The partners in research were Hohenheim University (Stuttgart), Agricultural University (Wageningen), the International Livestock Centre for Africa (ILCA), and ICRISAT. Areas studied were: animal capacity between and within species; effects of animal traction on growth and yield of millet and cowpea; comparison of the required forces for different toolbars and tools; and effect of different yokes on the tractive effort.

Objectives

Within the first subject, the following objectives were set:

- to determine average draught forces, power and work outputs for different species and different liveweights;
- to determine the relation between power and force and between work and force for all animals and species;
- to compare animals, within a species, based on average power and work output;
- to determine the differences in work output per day between using two bullocks as singles or as a pair; and
- to compare species, based on average power and work outputs.

Materials and Methods

Four animals of the same species were tested at the same time. Each animal had to pull a sledge with a fixed load for a maximum of 3 hours. Force required to pull the load was determined with a dynamometer the day before the test, under the same conditions. Times were taken every 200 m, and when the animal refused to continue. Distance was measured at the same points. When the animal stopped before the 3-hour limit was reached, the load was decreased for the next day's test. When an animal completed the 3 hours, the load was increased for the next day's test. Each animal was tested for four successive days.

The principle for the test was simple: load, thus pulling force, was fixed and known. Animal capacity is thus determined by the time an animal can pull and the distance an animal can cover with this load. Speed, work and power depend on these parameters:

speed	= distance/time (m/sec);	
work	= force × distance	(nm = joules);
power	= force × speed	(nm/sec = watt).

Since animals can pull different loads at different speeds, their capacities cannot be compared. Therefore the power parameter, which includes both aspects of traction, is extremely suitable to compare animals even when they are of different species.

The farmer will only be interested in the amount f work that can be done each day. Therefore the ork output, expressed in hectares/day, is the most nportant factor on which to compare animals.

Animals can accelerate and develop very high ower for a very short period of time. To determine iis maximum instantaneous capacity of animals, a raking device was used.

Temperature and relative humidity were ieasured every day. When a temperature-humidity idex differed more than two points from the verage, the test was repeated.

Comparison Between Animals Within a Species

To determine differences within species, animals f different body weights were taken when possible. or each animal the relation between force and ower was determined by regression analysis, based n the data of the four tests with different loads. laximum average force, power and work output er animal were also determined. All parameters ere related to animal liveweights.

Oxen Pulling Single and in Pairs

Four oxen from different liveweights were tested s singles. The same oxen were matched to form vo pairs consisting of two oxen of about equal veweights. These pairs were tested in the same way s the singles. Maximum average forces, power and ork outputs and the relation between power and orce were compared.

Comparison Between Species

All data for the four animals for one species were nalysed by regression analyses. These resulted in quations which described for instance the relation etween power and force for each species. To ompare the species all equations and maximum verage forces, power outputs and work outputs ere compared.

esults and Conclusions

Pulling force, power and work output all creased with increase in animal body weight. An crease in force required always led to a decrease speed, but nevertheless to an increase in power itput. Pulling with high forces could only be done r a short period of time and/or at a low speed.

Work output shows an optimum with increasing rces. Maximum work output is reached at a lower illing force than maximum power output.

Comparisons on liveweights, power and work itputs appeared to be most interesting.

Comparison Within Species

For horses weighing between 290 and 310 kg, ork output increased with the pulling force until a aximum was reached. Increase in force beyond this optimum resulted in a decrease in work output. For the horses of 290, 310 and 297 kg liveweight, the maximum work output of 6.28, 7.33 and 10.47 MJ respectively, was reached at a force of 670 N. For the remaining 295-kg horse this output was only 5.46 MJ, reached at a force of 548 N. Horses seem to be able to produce 18.5–23.6 kJ/kg liveweight. Only the 297-kg horse produced 35.3 kJ/kg liveweight which is significantly more.

Horses were tested pulling with forces from 14 to 40% of their liveweights. The highest powers were reached pulling with the highest forces: 889 N for three horses and 1133 N for the 297-kg horse. Powers generated were 1074, 1194 and 1302 nm/sec for the 290, 295 and 310-kg horses respectively, which suggests a relation between animal liveweight and maximum power output. For the 297-kg horse the maximum power of 1176 N was not in agreement with that theory. The average maximum power output appeared to be 3.7–4.2 nm/sec/kg liveweight.

The 297-kg horse performed remarkably better than the other ones for which no explanation could be found. It walked slowly but for a long time without resting, covering a long distance which resulted in a high work output. The 295-kg horse walked fast but only for a short period of time, which resulted in a high power but a low work output. The maximum average power output for these horses was about equal, 1176 and 1194 nm/sec, which was reached by pulling 1133 and 889 N respectively.

With the braking device, horses were able to pull for about 30 sec with forces of 3060–3340 N, being 103–115% of animal body weight. These maximum forces resulted in generation of 4055–4620 nm/sec of power.

Donkeys weighing between 100 and 140 kg were used. For three donkeys, the work output of 2.74–3.43 MJ was highest when pulling with 219 N, which was the lowest load pulled. This load was already about 16–18% of the donkeys' liveweights. For the 100-kg donkey, maximum work output was also reached at 219 N which was, on the contrary, the highest load this donkey pulled. This donkey did not produce more than 0.94 MJ of work. Donkeys produced between 19.6 and 25.7 kJ/kg liveweight. The lightest donkey produced only 9.4 kJ/kg.

Donkeys could not generate more power than 359 nm/sec at 332 N. They were capable of producing 2.3–3.0 nm/sec/kg body weight as power output when pulling for a maximum of 3 hours.

With the braking device, maximum forces

reached were from 400 to 480 N which is about 27–30% of animal liveweight. Maximum power outputs reached 358–392 nm/sec.

Camel body weights, and therefore power and work output, differed considerably. Work output increased with increase in required forces until a certain optimum was reached. For the camels weighing 355, 380 and 520 kg, work optima of 6.09 MJ were reached at a force of 438 N. The smallest camel, 175 kg, reached an optimum of only 1.03 MJ at a force of 331 N. For the heaviest camel 11.7 kJ/kg was produced while for the 355-kg camel, 17.1 kJ/kg was produced. Thus the higher the liveweight the lower the work output/kilogram liveweight.

The 520-kg camel generated power up to 1338 nm/sec while the 175-kg camel did not generate more than 425 nm/sec. Power output was 2.2–2.6 nm/sec/kg. Heavier camels show lower power output per kilogram liveweight than lighter camels.

Individual differences between animals can be found when they are compared pulling the same percentage of their liveweights. At 13%, work output appeared to be highest for the 355-kg camel. Power output increased with increasing liveweights. Pulling about 19% of their liveweight, the same results were found.

Single bullocks with liveweights between 294 and 485 kg were tested. For the heaviest animals, 485 and 455 kg, the maximum work output of 8.23 MJ was reached at a force of 658 N. For the bullocks weighing 314 and 294 kg the optima of 6.17 and 5.14 MJ were reached at forces of 439 and 548 N respectively. So, the heavier the bullock, the higher the optimum work output and the higher the force at which it was reached. Work output per kilogram liveweight ranged from 17.0 to 19.6 kJ for the bullocks weighing 485 and 314 kg, respectively. Thus the heavier the animal the lower the work output per kilogram.

For power output, animal liveweight was also most relevant. The lightest bullock generated a power of about 654 nm/sec at a force of 548 N while the heaviest bullock generated a power of 1021 nm/sec at a force of 883 N. Thus, the heavier the bullock, the higher its power output and the higher the force at which it is reached. Bullocks generated 2.1–2.2 nm/sec/kg liveweight, regardless of the weight of the animal.

By using the braking device, we found that increasing animal liveweights led to increasing power outputs and increasing forces at which this output occurred. Power was reached at forces of 93–145 N and ranged from 757 to 1601 nm/sec. These forces were about 30% of animal liveweight.

Oxen Working as Singles and as a Pair

Two factors are important: power and work output. Certain agricultural tasks require more force than a single bullock can provide thus pairs must be used. For many tasks a choice between singles and pairs must be based on the work output/day.

Forces ranging from 400 to 1000 N were tested both with single and with pairs of bullocks. The tests resulted in maximum time and distances covered pulling with a certain force. The relation between force and distance was established for singles and pairs. Work output in hectares was calculated assuming that a distance of 10 000 m had to be walked to finish 1 ha of work.

Until a force of 900 N is required, a pair produces less than twice the output of a single (Table 2). Thus in these cases, singles used one after the other result in higher final work output/day than used together as a pair. The lower the required force the higher the difference and the more advantageous the use of bullocks as singles will be. At a force of 900 N there is no difference, so both ways of using bullocks are equally efficient. Forces higher than 900 N require the use of pairs.

Comparison Between Species

For all species relations between all parameters (power and force, work and force, etc.) were determined.

Table 2. Work output in hectares/day at different forces for single bullocks and pairs of bullocks.

	Force (N)						
	400	500	600	700	800	900	1000
Singles (ha)	1.20	1.07	0.96	0.84	0.72	0.60	0.48
Pairs (ha)	1.55	1.48	1.41	1.34	1.27	1.20	1.13
Pair/single	1.29	1.38	1.47	1.60	1.76	2.00	2.35
difference (%)	55	45	36	25	13	0	–15

Difference = 100% × (2 × single – pair)/pair

Table 3. Equations describing the relation between power, power per kilogram liveweight and force.

Donkey:	P = 18 + 1.03 F	and	P/LW = 553.61 + 6.47 F
Horse:	P = 122 + 1.09 F	and	P/LW = 410.08 + 3.67 F
Camel:	P = -70 + 1.46 F	and	P/LW = 956.49 + 2.00 F
Bullocks:	P = 569 + 0.51 F	and	P/LW = 943.92 + 0.46 F
Single:	P = 162 + 0.88 F	and	P/LW = 1200.81 + 0.97 F

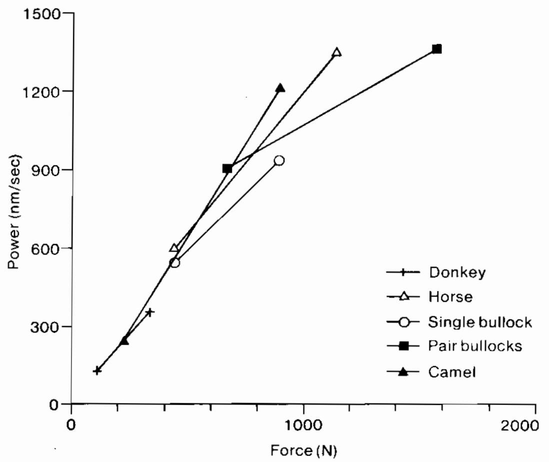

Fig. 1. Relationship between force (N) and power (nm/sec) for all species.

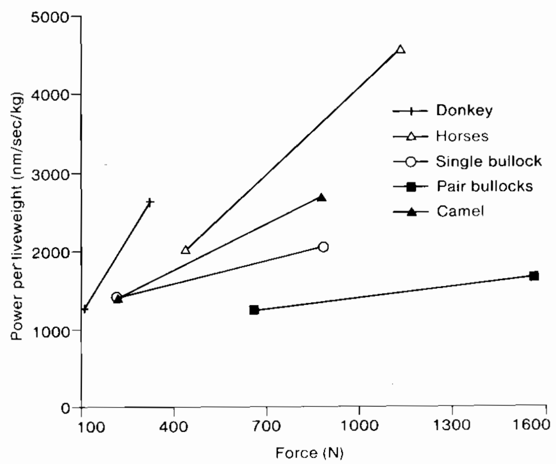

Fig. 2. Relationship between force and power per kg liveweight for all species.

The relation between force and *power* for all species is shown in Fig. 1. Analyses revealed that differences between levels and between slopes were significant, thus the relation is unique for each species. The relation between *power/kilogram liveweight* and force is shown in Fig. 2. The difference between levels and between slopes was still significant. Thus differences between species were not due to differences between animal liveweights.

The slopes for donkeys and horses were about equal so their power output depended in a similar way on force. Donkeys generated much less power than horses so the level of the line differed considerably. At forces up to the donkeys' maximum, power output per kilogram liveweight for donkeys was higher than for horses because donkeys walked faster.

Camels showed, at low forces, the lowest power output of all species. The line representing the relation between force and power appeared to be steeper for camels than for other species. Therefore at higher forces camels showed highest power output.

At forces between 650 and 900 N camels generated more power than horses or a pair of bullocks. At forces higher than 900 N camels could not perform. At forces from 1100 to 1500 N pairs of bullocks could still generate sufficient power to be used.

At very low forces pairs of bullocks generated almost twice as much power as a single bullock. The difference decreased when force increased from 400 to 800 N. Both slope and level differed significantly. Power output of single bullocks depended more on force (0.88 F) than on pairs (0.51 F). When power/kilogram liveweight was considered, the difference was even greater (0.97 vs 0.46 F). Equations and the absolute power outputs for all species are given in Table 3 and Fig. 3, respectively.

The relation between work output and force is not linear. Optima are reached for several species. When animals of the same liveweight of different species are compared, comparable work outputs are found. Horses of 300 kg for instance had equal work outputs as bullocks of the same weight, but at higher forces.

For the most important comparison between species, work output, expressed as hectares/day, has to be considered. Forces ranging from 400 to 1000 N were tested. The suitability of species appeared to depend on the force required.

Up to forces lower than 400 N donkeys can pull but they have the lowest work output. When a force

Table 4. Work output in hectares/hour and hours/hectare for singles and pairs of bullocks at different forces.

	Force (N)						
	400	500	600	700	800	900	1000
ha/hour							
Single (2)	0.47	0.45	0.44	0.42	0.39	0.36	0.32
Pair	0.51	0.49	0.47	0.45	0.43	0.42	0.39
hour/ha							
Single (2)	2.14	2.22	2.29	2.40	2.57	2.78	3.08
Pair	1.95	2.04	2.11	2.20	2.30	2.40	2.54
Singles/pair	1.10	1.09	1.09	1.09	1.12	1.16	1.21

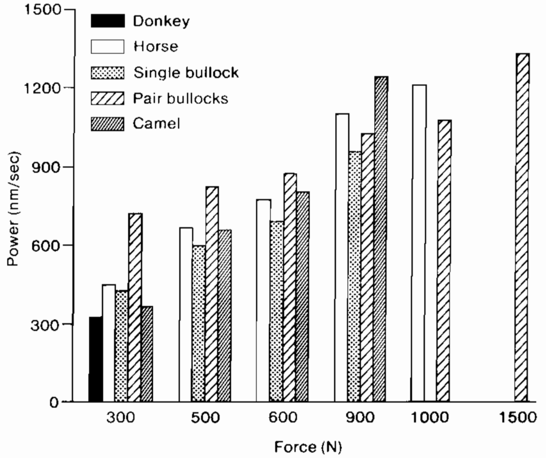

Fig. 3. Absolute power output (nm/sec) of species at different forces (N).

lower than 528 N is required, the work output in hectares leads to the following sequence from high to lower output: pair of bullocks, camel, horse, single bullock.

Horse and camel change place at a force of 528 N while camel and single bullock change place at a force of 529 N. The new sequence will then be: pair of bullocks, horse, single bullock, camel. Above a force of 540 N, however, horse and single bullock change places.

A pair of bullocks suited best in terms of work output especially at high force requirements. Horses, camels and single bullocks are equally good as long as forces do not exceed 530 N. Above 530 N, camels cannot keep up with horses and single bullocks, which perform equally well. Camels and single bullocks cannot pull with forces of 900 N and more. Horses can pull up to about 1100 N. Pairs of bullocks can pull up to 1500 N.

Discussion

A donkey of 120 kg liveweight can pull with a force of 280 N at a speed of 4 km/hour, generating a power of 319 nm/sec in the sledge trial. Goe reported a force of 140 N and a power output of 150 nm/sec for a donkey of the same liveweight and at the same speed. Forces as low as this one led to much higher speeds at the sledge trial (Goe 1983). Goe's data therefore suggest that donkeys are not suitable for any agricultural work as they are not strong enough. The sledge trial shows that one or two donkeys together can perform light tasks like shallow weeding for 3 hours/day.

Although donkeys cannot produce much draught force, not even relative to their liveweight, they are very strong as animals of burden. They can carry loads of 27–40% of the body weight at a speed of 5.6 km/hour, for 6–8 hours/day (Goe 1983).

Goe suggests that bullocks of 450 kg liveweight cannot pull more than 450 N at a speed of 4.0 km/hour. Power output is 500 nm/sec. In the sledge trial the 450 kg bullock pulled 883 N at a speed of 4.0 km/hour which is as much as the force of a 900-kg bullock in Goe's (1983) data at the same speed. Power output of the 450-kg bullock of the sledge trial is 1009 nm/sec for the 900-kg bullock of Goe. When a bullock had to pull with a force of about 450 N in the sledge trial, it increased its speed up to 4.7 km/hour. Thus the data from Goe seem to underestimate the real capacity of the animals.

The tests with the braking device revealed an important difference between horses and bullocks. Horses appeared to be capable of pulling 105–115% of their liveweights for about 30 sec, whereas bullocks cannot pull more than about 30% of their liveweights. The FAO reported much higher instantaneous efforts which exceed twice the weight of the animals in the case of equines, and equal the weight of bullocks (FAO 1972). The conclusion in both cases is that equines are much more suitable than bovines for work on fields which are not properly cleared. All animals tire quickly when performing tasks involving numerous peaks of effort.

For bullocks working at forces lower than 900 N it was better to use two singles rather than a pair. This may be so in terms of hectares/day but it is not the case when work output per person-hour is considered. Working with one single after the other will cost 10–20% more time/ha than working with the two as a pair (Table 4).

FAO (1972) stated that using a pair of oxen of the same strength meant that the tractive effort of a single ox working on its own must be multiplied by 1.9. The tests at ICRISAT indicated that this multiplication factor was not constant but depended on the force required.

Effects of heat stress on performance are shown by the results of the same tests done at different THIs (temperature/humidity indexes). The 294-kg bullock was tested twice at a force of 548 N. The work output was only 3537 kJ when THI was 81 but it was as high as 5141 kJ 3 days later when THI was 71. Thus performance decreases at increasing THIs. Premi (1979) showed that speed, power and work output depended on temperature and humidity. He found that these parameters were negatively affected by high THIs.

The equations of Premi cannot be used to describe the relationship between power, animal liveweight, draught and THI for the pairs used in the sledge trial. Consider a pair consisting of two 435-kg animals, pulling with 658 N at a THI of 75. According to Premi power output will be 0.76 hp which is 570 nm/sec, but in the sledge trial the output appeared to be 863 nm/sec. The same or even higher differences can be found for other pairs, draughts and THIs.

Conclusion

In Niger, the use of draught animals can lead to considerable increases in crop yields. In all regions different species of animals are present in various numbers. Therefore all species have to be judged on their draught capacity. Soil characteristics and climate differ in each region, therefore the required forces for soil tillage differ also.

With the relations between force and power output and between force and work output, the most suitable species can be selected when the required force is known. The information concerning animal species presented here may help to decide which species to use. The decision will be based on character, cost and draught capacity of the species. Information on the use of bullocks as singles and/or as pairs can be used by the farmers to decide whether they want to optimise hectares/day using singles or hectares/person-hour using a pair.

For many species a single animal is not strong enough to generate power of more than 900 nm/sec. Therefore pairs of horses and pairs of camels should be tested also.

Cows should also be tested. A comparison between bullocks and cows of the same breed and/or liveweight would be interesting, especially for farmers who cannot afford more than one or two animals.

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Section 6

Draught Animal Production: Health, Training and Management

Health in Draught Animals: An Example from West Java, Indonesia

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Abstract

Few observations have been made of the relative susceptibility of draught animals to specific diseases, compared to those in populations not used for draught. As a result of the stress involved in work, draught cattle are considered to be more susceptible to the generally occurring diseases. In addition they suffer ailments resulting directly from their use as draught animals. In this paper an attempt is made to identify some of the conditions which occur in animal populations used for draught in West Java, Indonesia.

Introduction

IN Indonesia there is little information concerning animal health or livestock productivity in cattle or swamp buffalo kept either for beef, draught, repositories of wealth or a combination of these. There is even less on the specific effects of disease on work output.

Methods

Following the application of animal health questionnaires to participating farmers in the project sites in Subang district (Santoso et al. 1987), a program of animal health visits was established with the intention of further defining animal health problems. Where possible animal health visits were arranged in advance and farmers asked to identify animals requiring attention. A history was taken from the farmer, and a complete physical examination of the animal was made. A clinical diagnosis or list of differential diagnoses were made on the basis of the history and physical signs, and these were confirmed where possible by appropriate laboratory examinations and response to treatment.

Where deaths or disease outbreaks occurred special visits were made to the field sites to investigate the causes.

In response to farmers' requests for veterinary drugs, a small survey was made of the costs and practicality of preparing low-cost remedies which could be applied by farmers to treat common conditions.

Results

Table 1 shows the frequency with which farmers presented animals with signs of ill health, and compares this with the frequency with which they reported the occurrence of signs of ill health in the previous questionnaire survey (Sumanto et al. 1987). One category (cough) was added to the list in order to account for all major presenting signs. It is striking that buffalo diarrhoea and skin conditions were presented most frequently. Diarrhoea was reported exclusively in calves up to the age of 3 months. Of the 15 skin conditions presented, 14 were lice infestation in buffalo calves housed in a communal stabling area.

Skin disorders were also frequent in cattle (5 of 14 cases presented), but in this case wounds figured

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Table 1. Farmer perception of frequency of occurrence of clinical signs (Sumanto et al. 1987) compared with observation by animal health patrol.

	Cattle		Buffalo	
Signs of ill health	Reported[a] (%)	Observed[b] (No.)	Reported[a] (%)	Observed[b] (No.)
Diarrhoea	05	2	55	9
Eye disorders	50	3	20	0
Harness sores	35	1	30	0
Weakness/thinness	35	0	25	0
Poor appetite	25	3	15	2
Nose discharge	15	0	10	0
Skin disorders	15	5	15	15
Limb conditions				
Stiffness	20	0	0	2
Hoof tenderness	10	0	10	0
Froth from mouth	10	0	0	0
Bloat	0	0	0	0
Abortion	5	0	10	0
Genital discharge	0	0	0	0
Cough	-	1	-	0

[a] Reported: 'Ever observed' by rearers in animals on that farm.
[b] Observed: Cases presented to animal health patrol.

Table 2. Faecal egg counts in swamp buffalo calves at Wanareja, West Java, Indonesia, and treatments given.

	First sampling			Piperazine	Second sampling			Piperazine
Owner	Toxocara	Strongyle	Strongyloides	treatment	Toxocara	Strongyle	Strongyloides	treatment
Ahwin	12800	-	-	+		dead		
Rustim	-	240	40	-		NT		
Arman	-	-	-	-		NT		
Eman	2800	-	-	+	-			
Oding	520	-	-	+	-	-	3320	+
Toto	11720	-	-	+	-	NT	-	+
Encling	1480	-	-	-	-	NT	-	+
Tamin	-	-	6440	-		NT		+
Kamin	-	-	320	-		NT		-
Tawad	-	-	1000	-		NT		-
Arma	-	-	1240	-		NT		-
Askim	9560	-	-	+		-	750	+
Sahrup	-	-	-	-	-	-	6940	-
Ito	5300							

NT: not tested.

more prominently and only one case of lice infestation was noted. Eye disorders, weakness/thinness, poor appetite and coughing were also reported.

Routine Health Visits

Internal Parasites in Buffalo Calves

Results of faecal examination of 14 calves presented on the animal health visits are shown in Table 2. Farmers complained of white scours in calves under 3 months of age, and of having seen round worms in faeces. They ranked this problem as more serious than the skin problems which they also commonly recognised. Examination of calves presented as having diarrhoea usually showed that they had pale, pasty faeces, but frank diarrhoea was not seen.

Toxocara vitulorum and *Strongyloides* spp. infections were noted. Treatment with 10 g Piperazine Citrate was effective in reducing *Toxocara* burdens, but in three cases *Strongyloides* eggs were present in faeces after treatment, although they had not been detected on initial testing 2 months earlier. One calf with a *T. vitulorum* egg count of 12 800/g of faeces died despite treatment with Piperazine.

Skin Disorders

Of the skin disorders presented lice infestation was most common in buffalo calves housed in a communal area. Farmers in general controlled lice by clipping the hair and rubbing with a type of leaf (Dadap, *Erythrina* sp.). Coumaphos (Asuntol, Bayer Indonesia) was recognised as effective by farmers but not used.

Wounds and burns were commonly reported. Burns from smut fires lit in the stable to control fly irritation were especially common. Signs of myiasis in wounds were not seen. One extensive burn on the flank of a cow was treated by the farmer by washing and daily application of fresh cow faeces as a poultice. A healthy bed of granulation tissue was formed and skin grew in from the edges leading to uneventful healing.

Farmers mentioned harness sores but none were presented during our visits, although one visit in January coincided with the end of work season.

A condition resembling scabies, with the skin on the head and neck in particular being thickened and having a squamous crusted appearance, was observed in a Java-type calf. It responded to topical treatment with 1% Coumaphos in vaseline. However, skin scrapings were not taken. Sarcoptic mange is stated not to occur in cattle in Indonesia (Sanguaranoud 1979).

Trypanosomiasis

One 5-year-old Javanese cow was diagnosed as having Surra due to *Trypanosoma evansi* infection. This cow had been losing weight over a period of 2 months and had poor appetite. On examination it had a temperature of 38.6°C and pale mucous membranes. Its packed cell volume was 14% with a haemoglobin concentration of 4.6 mg/100 ml. White blood cell count was $8.8 \times 10^3/mm^3$ with an absolute neutropenia. Faecal examination showed the presence of 1800 *T. vitulorum* eggs/g of faeces, and *T. evansi* were present in Giemsa stained thin blood films.

Other Disorders

Eye problems were presented in which there was reddening of the conjunctiva and mild blepharospasm but no cause was determined.

Farmers complained of poor appetite in some cattle and buffalo, but these animals usually appeared to eat normally when offered food.

Disease Presenting in Outbreak Form

Deaths in Buffalo Calves

In 1988 the buffalo calving season occurred in the dry season between May and July. High mortality was observed in two villages with 30% of the calves dying between 2 and 4 months of age. Five of the 12 deaths occurred in July, 4 in August and 3 in September, with diarrhoea and weakness as the signs predominantly reported by farmers.

Deaths appeared to be primarily due to inadequate forage availability for the buffalo cows and their calves, exacerbated by internal parasitism. Surviving calves were infected with *T. vitulorum*, high egg counts, and unthriftiness and diarrhoea were seen in some cases.

Red Urine in Cattle

In one village five cattle were reported sold because they were 'sick' and had red urine.

Malignant Catarrhal Fever

Two buffalo were reported to have developed typical signs of malignant catarrhal fever and were sold. These cases were associated with contact with sheep which had recently lambed.

Discussion

This study attempted through the use of regular animal health visits to identify and document some of the animal health constraints to draught animal power in Indonesia. The method used was determined by limited availability of funds and staff, and does not attempt to be a quantitative epidemiological study of health problems in draught animals. However, in view of the paucity of information available it was felt that a useful start could be made on problem identification through questioning of farmers, examinations of animals identified as being sick and by observation during visits. In some cases, where suitable laboratory testing is available, this may lead to closer definition of problems.

Farmers in the study area had previously responded to a questionnaire in which they were asked to rank a selection of clinical signs by frequency of occurrence (Sumanto et al. 1987). Common occurrence was reported by less than 3% of all rearers for all conditions, except diarrhoea which was common on 7% of farms.

Although the draught animal owners who participated in these studies do not keep records, they were able to give an account of presenting signs of ill health which predicted those observed by an animal health patrol visiting them on a regular basis. Farmers were certainly aware from their own observations of the importance of diarrhoea associated with worm infestation in young buffalo calves, and this view is supported by the data collected during the course of farm visits. High levels of faecal egg counts associated with *T. vitulorum* were frequently seen and were associated with the clinical signs of unthriftiness and diarrhoea described for this condition. There were also frequent, although varying, levels of infestation with *Strongyloides* sp., although their significance in these West Java villages is not known. Buffalo calves appear to be more susceptible to *T. vitulorum* than cattle and the parasite is reported to predispose diarrhoea which may be fatal (Chaudry 1978), although this parasite is not mentioned in a review of diseases affecting draught power in domestic animals in Indonesia (Partoutomo et al. 1985). The observations recorded in this paper, however, suggest that toxocariasis may be an important constraint to production of draught animals in Indonesia.

The list of clinical signs offered to farmers for assessment in the previous questionnaire encouraged farmers to rate chronic conditions as of greater importance than acute, rapidly fatal conditions. There was, for instance, no opportunity to rank 'found dead' in the list of clinical signs. However, it is evident from our observations that acute conditions leading to rapid disposal of the animal do occur. Farmers are reluctant to treat animals which they consider to be seriously ill, since in the event of death of the animal only a small fraction of its value may be recovered. A larger portion of its capital value is preserved by its rapid sale as a casualty.

On the other hand the treatment of chronic conditions, particularly skin ailments, inspires considerable effort and ingenuity and farmers' ranking of these conditions may partly reflect this.

The method of periodic health patrols reported in this paper also favours recording and documenting of chronic conditions since these are more likely to be presented by farmers. In addition, diagnosis is likely to be more accurate, whereas retrospective diagnosis of diseases affecting animals which have been removed from the population is difficult. For this reason, although helminthiasis was documented as a problem, no diagnosis could be made of diseases which resulted in the disposal of numbers of adult stock.

Recording of production, and particularly of disease effects on production, is difficult where livestock holdings are small and dispersed and there is little incentive for on-farm recording by farmers. In order to define the effects of animal health problems on the draught animal system, a high intensity of surveillance by the investigators is required so that all incidents of disease are recorded and the production and economic background in which they occur are defined. In the recorded population these data may then be supported by the results of serological surveys and treatment trials and used to evaluate the importance of disease in the production system.

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Diagnostic Techniques for Foot-and-Mouth Disease in Southeast Asia

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Abstract

Foot-and-mouth disease (FMD) is a highly contagious disease of livestock, affecting all cloven-hoofed animals. It is generally not fatal but has a marked effect on the productivity of livestock. While most countries in Asia are endemically infected, the disease has been eradicated from Indonesia and Malaysia.

An ACIAR project in Thailand, involving the Thai Department of Livestock Development and the CSIRO Australian Animal Health Laboratory, has involved the development and application of antigen detection and virus isolation procedures for primary diagnosis, the determination of antigenic variation of FMD virus types in Thailand and the development of antibody and antigen assay procedures.

ELISA methodology has been applied to antigen detection and antibody assay and the methodology should be applicable to other countries, either for routine diagnosis in an endemic situation or as a provision for rapid diagnosis in the event of a suspected outbreak of FMD in a country where it does not normally occur.

Introduction

FOOT-AND-MOUTH disease (FMD) is one of the most contagious of livestock diseases. It is caused by a virus and affects all cloven-hoofed animals including ruminants and pigs. Most countries in Africa, Asia, South America and Central and Eastern Europe are endemically infected with the disease. Those countries which are free enjoy substantial benefits in productivity and access to export markets. For both of these reasons, there is considerable emphasis on control or eradication of FMD in infected countries.

Nature of the Disease

The most apparent signs of FMD are the development of vesicles (blisters) in the mouth and on the feet, causing a reluctance to eat and lameness. Vesicles also occur on the snouts of pigs and the teats of cows. Affected animals have a fever, salivate excessively, are reluctant to move and may lie down for long periods. Anorexia results in a loss of condition and a decrease in lactation. Draught animals may be unfit for work for up to 6 weeks and cows may stop producing milk for the remainder of a lactation, with a reduced milk yield in subsequent lactations.

Internal effects of the virus can include sudden death through cardiac failure in young animals and chronic ill-thrift in older livestock. While FMD is generally not fatal, mortalities of up to 10% often occur in young animals.

Two aspects of FMD are of particular significance in developing country agriculture enterprises. The first is that the disease spreads rapidly when susceptible livestock are intermingled with infected animals, especially in climatic conditions of high humidity, and when animals are under stress. Commonly in tropical countries this is manifest by FMD outbreaks occurring at the commencement of the monsoon season, a time when draught animals are in maximum demand for preparation of rice

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fields for planting. Since the disease may affect a large proportion of animals in a village or larger area at the same time, this can result in delays in planting and a subsequent loss of crop production.

The second aspect of FMD is the fact that the disease tends to have a much greater effect on highly productive livestock than on unimproved native animals. Thus, while the effects of FMD may be incompletely appreciated, and therefore tolerated, in an undeveloped agricultural enterprise, attempts to upgrade production by the introduction of genetically superior livestock may be devastated by outbreaks of the disease. Improved livestock production therefore demands improved control of FMD.

FMD in Asia

Most Asian countries are infected with FMD and exercise some level of disease control, by restrictions on livestock movement and by vaccination. The disease was eradicated from Indonesia in the late 1970s with the assistance of the Australian International Development Assistance Bureau (Bain 1982) and has remained free since then, with the exception of an outbreak in 1983 which was quickly and efficiently eliminated. Singapore has been free of the disease for many years and Malaysia is generally free, with infrequent outbreaks which are quickly controlled. China is apparently free of FMD and maintains constant vigilance along its land borders with affected countries. The disease is a major cause of economic loss in other countries, including India, Burma, Thailand and the Philippines.

Of the seven different serotypes of FMD virus, four (types O, A, C and Asia 1) occur in Asian countries. Each serotype is antigenically distinct, and there are finer antigenic differences within a serotype. Vaccines can provide good protection against the disease, if used in conjunction with quarantine and movement control. However, they must be of the appropriate serotype and strain. Laboratory diagnosis is required to confirm clinical evidence of disease and to determine the antigenic nature of the particular virus strain.

The ACIAR Project

Improved diagnostic procedures have been the basis of research undertaken in Thailand over the past 3 years by staff of the Department of Livestock Development, in collaboration with CSIRO Australia and with financial support from ACIAR.

The objectives of the project were as follows:

(1) The development and application of improved FMD virus typing methods.
(2) The development and application of appropriate FMD virus isolation procedures.
(3) The determination of antigenic variation of FMD virus types in Thailand.
(4) The improvement of procedures for antibody measurement and application to vaccine evaluation and epizootiological investigations.
(5) The accurate estimation of 140S antigen concentration in FMD vaccine batches.

The most rapid means of confirming a clinical diagnosis of FMD is by detection of viral antigen in specimens of epithelium. Australian staff working at Pirbright in England (Roeder and Le Blanc Smith 1987) perfected an improved antigen detection procedure using enzyme-linked immunosorbent assay (ELISA). This procedure was used in Thailand and found to be highly sensitive and specific (Westbury et al. 1988a). Viral antigen is detected within a few hours of receipt of the specimen, and the serotype identified. In recovered or vaccinated animals, the immune status can be evaluated by antibody measurement and again, rapid and economical methods were devised to carry out these assays (Westbury et al. 1988b). Research is currently being undertaken to develop improved methods of strain differentiation and to apply these to viruses isolated from field outbreaks. To date, the evaluation of strains of type O and type A viruses has been of particular benefit in the selection of vaccine strains to achieve optimum protection.

A 3-year extension of the project has been proposed to continue the laboratory-based research and to initiate epidemiological studies, with an emphasis on monitoring the efficacy of vaccines.

A review of the project in December 1988 recommended that an extended project should emphasise the following:

(a) epidemiology of FMD in Thailand;
(b) economic impact of FMD in Thailand;
(c) antigen variation using ELISA techniques;
(d) antibody detection by ELISA; and
(e) 146S antigen determination by ELISA.

In effect, there would be a move towards application of the laboratory methods developed, and to evaluation of the impact of the disease in the field. In most Asian countries in which FMD is endemic, there are few data on which to assess the real economic effects of the disease, and it is hoped that this project will address some of those deficiencies.

It is intended that some benefits of the project should be realised by other Asian countries and it is planned to make the technology available to other laboratories where it can be put to good use in establishing improved diagnosis for FMD.

The Thai FMD Research Center at Pak Chong has been nominated by FAO as the Regional Reference Laboratory for FMD, and as such is in a position to assist other Southeast Asian countries with aspects of FMD diagnosis. One of the major continuing goals of the ACIAR project is to provide support to the Laboratory, to enable it to perform in this capacity.

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Control of *Toxocara vitulorum* in Calves of Working Buffalo

J.A. Roberts*

Abstract

The importance of a live and healthy calf for the productivity of working buffalo is emphasised, in view of the short duration of work in paddy cultivation and relatively poor reproductive performance. The extraparasitic life cycle and the parasitic life cycle of *Toxocara vitulorum* are described in relation to the pathogenesis of toxocariasis. A procedure of preventive treatment has been developed, based on the observation that transmission of larvae from the cow to the calf through the milk has ceased before the calf is 10 days old. Calves treated when 10 days old with an anthelmintic which is effective against immature parasites (pyrantel or levamisole) are not affected by the parasites and do not recontaminate the environment with eggs.

Introduction

In most rice-growing areas of Sri Lanka draught buffalo work for about 10 weeks/year (de Silva et al. 1985), so any supplementation to their productivity is welcome. The obvious complementary activity is to produce calves with or without sale of milk. In either case it is essential to have a live calf, as the cow's own calf is required to stimulate milk let-down. Calving intervals range from 13 to 24 months (de Silva et al. 1985), and substantial funds are being invested on research in Asia to improve reproductive performance. Clearly then if the buffalo owner has a calf on the ground, a small outlay to keep it alive, or to improve its growth rate, is a good investment.

Toxocara vitulorum is a significant cause of mortality and reduced growth rate in buffalo calves. In extreme situations, before the modern anthelmintics became available, mortality rates up to 80% were recorded (Das and Singh 1955). The parasite can also be a predisposing factor for enteric infections (Chaudhry 1978). In spite of the availability of effective anthelmintics the parasite is still a problem for village buffalo owners and on institutional farms. The Australian Centre for International Agricultural Research (ACIAR) has had a collaborative project with the University of Peradeniya to study the life cycle of the parasite with a view to developing appropriate procedures for control of the infection. The result is a single preventive treatment which removes the infection before it can have a pathogenic effect, and which prevents recontamination of the environment. This paper describes toxocariasis and the new preventive treatment procedure and gives the results of field trials with the treatment.

The Mature Parasite occurs in the duodenum of calves between 3 weeks and 3 months old. It is a large ascarid (20–30 cm by 0.4–0.6 cm) with a soft, partly transparent cuticle so the white reproductive organs can be seen through the cuticle when the worm is fresh.

Egg Production typically commences when the calf is 23 days old, rises to a peak around 5 weeks and almost immediately commences declining to become zero before 3 months (Fig. 1). The parasites are packed into the duodenum until near the end of the egg production period when they are passed out

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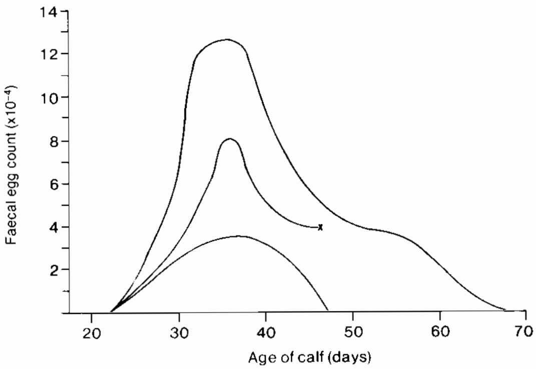

Fig. 1. Faecal egg counts of *Toxocara vitulorum* in buffalo calves.

within a few days. Peak egg production ranges up to 300 000 eggs/g of faeces (epg). This represents around 100 000 eggs/mature female worm/day and up to about 50 million eggs are produced by each calf before the infection is shed. Usually peak egg counts range from 20 000 to 100 000 epg.

The Extraparasitic Life Cycle commences when the faeces containing eggs are passed to the environment. On moist soil it is rapidly incorporated into the surface layers by the action of insects and the eggs mature in about 16 days when average daily maximum temperatures are around 28°C. In cooler conditions development is slower, and eggs do not mature below 19°C. If the infected faeces are passed into water, which is not unlikely considering the behaviour and husbandry of buffalo, the development is determined by the availability of oxygen, and is intermittent as oxygen becomes available by stirring of the water by wallowing buffalo, or the wallow is flushed with fresh water from rain (Roberts 1989a). Development under these conditions can take months. Some eggs rise to the surface of the water on small rafts of organic matter and these develop more rapidly. Whether in soil or water, if the temperature does not get too high (>35°C for prolonged periods), or the humidity too low (<80% RH for prolonged periods), the infective egg can survive for at least 15 months (Roberts 1989a). Consequently there are eggs in the soil, in the water, on the pasture, on the hair of cow and calf, around the milking area, in the sheds . . . everywhere the calf has been, and there is warmth and moisture, infective eggs are found (Roberts 1989a). Buffalo calving in the tropics is determined by the availability of feed — increased feed stimulates ovarian activity so that in about 2 months conception occurs and the calf is born about 10 months later. In many areas this cycle is determined by the monsoon season, and the calf is born in the next monsoon season when conditions are favourable for feed for the cow and thus for her milk supply and the growth of the calf (Lundstrom et al. 1982). The same warm and wet conditions are favourable for the development of *T. vitulorum* eggs, so there will be calves contaminating the environment at the same time as there are cows in late pregnancy.

The Parasitic Life Cycle starts when a cow consumes infective eggs from the environment. The eggs hatch in the small intestine, the larva penetrates the mucosa in the crypts, enters a capillary and is taken in the portal vessels to the liver. Most larvae remain in the liver. Some move to the lung over about 2 days and a few go to other organs such as muscle, kidney, or brain. During migration and in the organs the larvae are surrounded by inflammatory cells, particularly eosinophils. Presumably many larvae die but some persist in the tissues of the cow for more than a year without affecting the cow. The larva does not develop significantly unless the host is a cow and the cow becomes pregnant. Late in pregnancy the reproductive cycle of the cow and the life cycle of the parasite become synchronised, and some of the larvae recommence development in the liver and lungs. A few days before parturition larvae migrate to the mammary gland where they complete their development to the stage which is infective for the calf. A few of these larvae move into the colostrum in some cows, but in most cows larvae first appear in milk after 24 hours (Roberts 1989b), and the numbers reach a peak by the time the calf is 3-4 days old. The migration of larvae into the milk is complete before the calf is 10 days old (Table 1). The larvae develop and grow in the duodenum of the calf. The prepatent period is about 23 days. The pattern and duration of egg production are described above.

The Pathogenesis of the infection is attributable to the bulk of parasites in the duodenum. In extreme cases very large numbers of immature parasites are claimed to kill calves. A usual worm burden would be 100-200 worms, slightly more than half of which are females; however, several times that number may be present. The large bulk of parasites reduces feed intake, and impairs digestion and absorption of nutrients (Enyenihi 1969). Consequently the condition is most serious when the level of nutrition is low, such as when the cow is not producing enough milk, or the owner is taking too much milk

Table 1. Mean number of *T. vitulorum* larvae present in the milk of buffalo cows. The volume of milk is that produced from days 3–28 after parturition.

Before parturition	Before suckling	Time of milk collection relative to parturition (days) 0	1	2	3	4	5	6	7	8	9	10	11–28	Volume of milk (ml) (mean ± SD)
2	1	6	16	17	14	15	8	5	2	2	0	0.2	0	2152 ± 665

Table 2. Minimum age for preventive treatment of *Toxocara vitulorum* in buffalo calves with anthelmintics effective against immature parasites.

Age when treated (days)	Proportion developing patent infection[a] Pyrantel	Levamisole
1–3	–	15/16
4–7	12/20	23/43
8–9	1/10	1/15
10–16	0/17	1/13
17–20	0/2	0/4

[a] Number infected/number treated; 19/20 controls developed patent infections.

for family use or for sale. The parasite feeds only on the contents of the intestine, so does not damage the mucosa unless the worm burden is very heavy, when the intestinal wall becomes stretched and attenuated and may become ulcerated (Srivastava and Sharma 1981). Rare sequelae are intussusception (Sprent 1946) and perforation of the intestine (Srivastava 1963).

Diagnosis of severe cases is based on the clinical signs of poor body condition, depression, steatorrhoea and a butyric odour on the breath and from the faeces. Usually the faeces are pasty in consistency and light grey-green in colour; however, diarrhoea and constipation sometimes occur. Most patients would be 5–9 weeks old and would not have been treated with an effective anthelmintic at the correct time (see below). All patients would be between 3 weeks and 3 months old. Faecal egg counts are very helpful for herd diagnosis and for epidemiological studies, but can be misleading in individual patients. Unless egg counting facilities are available immediately, the clinician should not delay treatment while awaiting the result of a faecal egg count.

Clinical Treatment of cases of toxocariasis should be directed to getting rid of the parasites and possibly providing supportive therapy if it is indicated by the state of the patient. Anthelmintics which are sufficiently effective against mature parasites include the imidazothiazoles (pyrantel, levamisole and morantel), piperazine, the organophosphates (haloxan, trichlorphon and naphthalaphos) and the benzimidazoles. Phenothiazine and thiabendazole are not adequate.

Electrolyte imbalances occur late in the disease and it might be expected that fluid and electrolyte therapy would be beneficial, however no contolled clincal studies have been done to confirm the benefit of such therapy.

Preventive treatment is clearly the most satisfactory approach as there are many problems associated with treating clinical cases, and clinical cases are just the extremes of a very large number of young calves, the growth of which is stunted by the presence of adult *T. vitulorum*. The observation that mammary transmission has ceased within 10 days of calving gives us the key to preventive treatment. An anthelmintic which is effective against immature parasites, given to 10-day-old calves, will forestall the pathogenic effects of large numbers of immature parasites and of mature parasites, and will preclude further contamination of the environment with infective eggs, because the infection will not become patent. Anthelmintics which are effective against immature parasites are pyrantel and levamisole. The benzimidazoles and prebenzimidazoles are usually, but not always, satisfactory and piperazine is not effective. It is important to note that anthelmintics which are effective against mature parasites (see under clinical treatment) are not necessarily effective against immature parasites.

Pyrantel is recommended because it is cheap, US$0.15 per calf, readily available in tablets of appropriate dose because it is used in human medicine, and has a high therapeutic index. One dose rate (250 mg) of pyrantel can be used for all buffalo calves from 15–35 kg body weight. Treatment with pyrantel at 10 days is recommended for all calves. On institutional farms or in dairy cooperatives it is possible to simplify the protocol. Treatment at 16 days of age is just as effective as treatment at 10 days, so one day of the week can be selected, and on that day every week, all calves 10–16 days old should be treated. This treatment procedure has been extensively tested in the field and it works. If treatment is given too early (before 10 ys) the calf may be reinfected through the milk. treatment is given too late there will be the ssibility of pathogenic effects before the atment, and there will be further contamination the environment with infective eggs. However, if atment has been given too early, or not at all, lves less than 10 weeks old should still be treated. r the well-being of the calf and perhaps its life, atment is better late than never.

Extension materials have been developed to omote the new treatment procedure, but the nefits will only reach village buffalo owners if ere are informed concerned people serving them iere they obtain their veterinary advice and dicine. This should be from the veterinary geon, but may be from the pharmacist or from milk collecting centre of a cooperative.

Field Trials on institutional farms have given solute control even when the procedure has been plemented by an instruction from Head Office d extension material has been provided to vestock Officers. This is not just control of the ease, but also control of the parasite, so that ntamination of the environment has ceased. In lage trials the procedure has been just as ccessful where there is an effective extension vice which provides a livestock development ckage. In village areas where information is made ailable, but the initiative for treatment is left with buffalo owner, there is a decrease in the idence of infection but not all calves are treated. such areas it will be necessary to provide ormation to village buffalo owners through their rmal suppliers of livestock medicines, particularly pharmacists, veterinary surgeons and the staff of milk cooperatives.

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ELISA for the Improved Diagnosis of Animal Disease in Southeast Asia

B. Patten*

Abstract

The ACIAR-funded project on 'The Establishment of Improved Methods for the Diagnosis and Control of Livestock Disease in Southeast Asia using Enzyme Linked Immunosorbent Assay (ELISA)' involves the Regional Veterinary Laboratory, Benalla, of the Department of Agriculture and Rural Affairs, Victoria, Australia, in collaboration with the Research Institute for Veterinary Science (Balitvet), Bogor, and the Universiti Pertanian Malyasia. The project was established with the broad aims and objectives of developing diagnostic tests based on ELISA technology. The diseases that the project is primarily concerned with include:

Brucellosis in cattle, buffalo, sheep, goats and pigs,
Anthrax in cattle, buffalo, sheep and goats,
Haemorrhagic Septicaemia in cattle, buffalo and pigs,
Leptospirosis in cattle, buffalo and pigs, and
Newcastle disease in poultry.

The project also has as one of its ojectives to assist the transfer of the developed ELISA technology into the regional diagnostic laboratories operated by the Directorate General Livestock Services, Directorate of Animal Health (Keswan) of the Indonesian Department Pertanian.

Introduction

DISEASE is one of the limiting factors to increased animal production. In the developing world this is exacerbated by the fact that a large number of animals are held in smallholdings and so the loss of, or decreased productivity of, only one animal can result in severe economic loss for the farmer.

One of the constraints to disease control is the lack of effective disease diagnostic systems which may be due to:

i) costs —lack of funds for a diagnostician to travel
lack of field or laboratory reagents and materials
lack of funds to transport samples to a laboratory

ii) the nature of the reagents — materials may not be able to be stored for long periods of time or require specialised storage conditions

iii) inappropriate or contaminated samples — the right sample to diagnose the disease was not submitted or was not stored or transported properly to the laboratory

iv) lack of laboratory facilities — sophisticated laboratory hardware is frequently required for the newer diagnostic tests being introduced.

ELISA has achieved a high degree of acceptance because the test:

— can be done at low cost per unit sample
— has high sensitivity
— depending on the format, may be able to be used by minimally trained people in the field
— can be semi or fully automated for large-scale epidemiological investigations
— can be adapted to specific local requirements

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- — is simple to perform
- — uses low volumes of reagents
- — can be adapted to detect either an antibody-serological response to an agent, or to detect the presence of an antigen or chemical.

How Does ELISA Work?

The assay works basically by attaching an antigen such as a bacterial, viral, or parasitic cell or cell component onto a solid immobile phase such as a polystyrene plastic tray which has 96 wells, or onto some other solid phase such as a test tube or a polystyrene stick or bead.

A test sample is then added and in the case of a serum sample, any antibody specific to the initial antigen binds strongly to that antigen.

Another antibody is added which has an enzyme linked to it. This second antibody, or conjugate, is specific to the species from which the test sample was taken.

The presence of the enzyme is detected using a substrate which changes colour. The degree of colour change is measured using a Reader which measures the absorbance of the substrate, although in a number of cases the reaction can be read by eye, if just a positive or negative result is required.

ELISA, as with most biological assays, does have some disadvantages:

- — each particular assay must be fully researched and standardised in a laboratory that is competent to do this before the test can be used for general field work;
- — the final test *can* be adapted for use as a field crush-side test; however it is generally laboratory-based. Depending on the type and set-up of the test, some laboratory hardware is required for the performance of the assay;
- — the assay is highly sensitive, detecting in the region of <50 ng (10^{-8} g) of antibody or antigen; however problems may be encountered with specificity which can cause difficulties in the determination of a diagnostic end-point or positive/negative cut-off. Sufficient research and development is needed to determine the significance of the results prior to the use of the test in the field or diagnostic laboratory.

The project at Balitvet is concerned with the use of ELISA for the diagnosis of Brucellosis, Haemorrhagic Septicaemia (HS), Anthrax and Leptospirosis. The use of ELISA for the first three diseases would be of main interest in the draught animal area.

The diagnosis of Brucellosis in the field presently involves the testing of serum samples using the Rose Bengal Plate agglutination Test (RBPT). This test has a high degree of sensitivity but a low level of specificity, thus giving many false positive reactions. The test is also subjective relying on the ability of an operator to grade an agglutination reaction. The RBPT is therefore of use only as a screening test with positive samples being confirmed using a more specific test. The confirmatory test presently used is usually the Complement Fixation test (CFT). This test is difficult to standardise and requires reagents such as complement which are highly heat-sensitive, and so the test is not available in all of the A grade diagnostic laboratories in Indonesia.

An ELISA for the serological diagnosis of Brucellosis in cattle and buffalo has been established at Balitvet and is being used routinely. The test is being compared with the complement fixation test to establish the sensitivity and specificity of the assay in comparison with the conventional tests. The assay is also being distributed to the regional diagnostic laboratories as they become equipped to perform ELISA. The test is basically laboratory-based, and therefore samples still need to be screened using the RBPT. However, the ELISA can take the place of the CFT as it is far simpler to perform, uses reagents which are more stable and far cheaper than CFT reagents and has a level of sensitivity and specificity which are comparable to the CFT. The ELISA should therefore be of value for general use in the laboratory, and will also be of use in association with the Indonesian Government's program to control and eradicate Brucellosis from the main cattle breeding areas of South Sulawesi, and the Eastern Islands comprising Nusa Tenggara Timur and Nusa Tenggara Barat.

HS and Anthrax are considered diseases of high economic importance in Indonesia; however laboratory confirmation of the diseases is rarely performed. Standard methods are available for the laboratory diagnosis of both of these diseases so why do we need an ELISA for this purpose?

It is generally found that the proper samples necessary to confirm the diagnosis of the diseases are not submitted to the laboratory. The type of samples required are a thin blood smear and a swab collected using a sterile swab stick and transported to the laboratory in transport media to arrive within 1-2 days after collection. What usually arrives, if anything, is a thick blood smear which cannot be examined under the microscope, and a dried out swab of cotton wool from which no organisms can be grown. The final diagnosis in a lot of cases therefore relies on the ability of the field staff to recognise the individual diseases which are clinically similar. Notwithstanding the need to have properly trained field staff, the ELISA presently being developed is designed to allow the diagnosis of disease using the samples presently submitted, or by using more appropriate techniques for the collection and submission of samples such as filter paper disks which are far easier to store and submit than swab or blood samples.

ELISA for the diagnosis of Haemorrhagic Septicaemia (HS) and Anthrax are still in the development stages. However progress to date has been the development of an ELISA to determine whether or not an isolate of *Pasteurella multocida* (the causative agent of HS) will cause HS. This is of importance as *Pasteurella* can be isolated from clinically normal cattle, and as a postmortem contaminant. Cattle can also be infected with at least four different types of *Pasteurella* of which only one will cause HS. The HS antigen ELISA presently needs a pure culture of the organism. However it is hoped to increase the sensitivity of the assay such that circulating organisms in an animal can be detected.

An ELISA is also available to detect the antibody response of animals infected by natural infection, or injected with vaccinated HS organisms. Presently the specificity of this test has not been fully verified to ensure that only antibodies to HS organisms are detected, and not cross-reactions to the other *Pasteurella* organisms.

In the area of Anthrax an ELISA has been developed which will detect Anthrax toxin, and we are also able to detect the antibody response of an animal vaccinated with anthrax spore vaccine to this toxin. It is again hoped to be able to improve the sensitivity of the assay to detect circulating anthrax toxin in animals infected with *Bacillus anthracis*.

The ability to detect either HS antigen or Anthrax toxin circulating in animals will obviously assist in the laboratory diagnosis of these diseases. The ELISA for the detection of antibody to the agents which cause HS or Anthrax may be of use:

(i) to survey for antibodies in animals from areas thought to be free of the disease, so confirming the presence or absence of the disease;

(ii) to provide information on the prevalence of the disease in certain areas; and

(iii) to provide information to field staff on the antibody status of animals previously vaccinated against the diseases.

It is hoped finally to be able to equate the antibody level or titre detected in the animals with protection to infection, allowing an appraisal of whether revaccination is required.

Acknowledgments

Such uses of the assays require the continued development of the tests in the laboratory. We are grateful for ACIAR's continuing financial support in this work.

Training and Handling of Oxen for Work in Zimbabwe

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Abstract

This paper describes the role of draught oxen in Zimbabwe, and the program for the training and handling of draught animals at the Institute of Agricultural Engineering, through courses for extension staff and other instructors in the field.

Introduction

AGRICULTURE plays a vital role in the economy of Zimbabwe in ensuring the nation's self-sufficiency in food. Agriculture currently provides Zimbabwe with more than 90% of its food requirements, and accounts for 41% of total merchandise exports. More than 70% of Zimbabwe's population live in the rural areas and derive their income from farming. The country lies to the north of the Tropic of Capricorn and almost the whole country is more than 300 m above sea level.

Farming Sectors

Agriculture in Zimbabwe is based on four farming sectors: (1) communal farming; (2) resettlement farming (land redistribution area); (3) small-scale commercial farming; (4) large-scale commercial farming (including state farms) (Table 1).

In the communal areas the land is owned by the community. The arable land is only allocated to a family (farm-household) to cultivate. This allocation can be withdrawn. Grazing land is communally used.

Food Production

Maize is the major food crop in Zimbabwe and in 1987 the communal area farmers produced 1.45 million t which accounted for 64% of the total production. In addition to this, these farmers retained over one-half of their maize production for their own consumption. In 1985 communal farmers sold 675 000 t of maize to marketing authorities; commercial farmers, 1 153 000 t (CSO 1987).

Draught Cattle

In the communal farming sector in Zimbabwe, animal draught is of prime importance for farm operations. Draught animals are used for tillage, weeding and transport with ox-carts. The distribution of draught animals varies in different agroecological regions. In the communal areas about 80% of the farm-households own cattle and 40% have sufficient draught power, that is, a team of four oxen.

Bratton (1984) found that peasant farmers in Zimbabwe universally expressed the view that four oxen are required to form a draught team and that two oxen were inadequate (Table 2).

Draught Power Shortage in Communal Areas

About 90% of the draught power used by communal farmers is derived from draught animals, mainly cattle. The main functions of cattle are to form capital (*lobola*, cash) and draught power for tillage and transport. The Central Statistical Office (CSO 1987) estimated that there were roughly 3 million cattle in the communal areas in 1984. During the war of independence (1977–80) more than 1

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Table 1. Characteristics of farming sectors (1987).

Farming sector	No. of farms	Permanent labour force	Farm size (ha)	Total area ('000 ha)
Communal	860000	2-4	1-5*	16350
Resettlement	-	-	5**	3000
Small-scale Com.	8600	-	124	1420
Large-scale Com.	4500	30	2200	12000

Source: Central Statistical Office (1987) and AGRITEX data.
* 1-5 ha arable plus communal grazing which divide into roughly 10 ha grazing/family.
** Resettlement on purchased commercial farms either takes place on an individual family basis or as a cooperative. The individual family farm is 5 ha plus communal grazing for animals.

Table 2. Ownership (percent) of cattle and draught.

Household characteristics	Wedza $n=184$	Gutu $n=144$	Chipuriro $n=97$	Overall $n=425$
Cattle Ownership				
Own cattle	75	83	82	79
Own 10+ cattle	26	31	27	28
Own no cattle	25	17	18	21
Draught Ownership				
Own 2+ oxen	57	63	65	61
Own enough draught (4+ oxen) (Objective measure)	35	46	49	42
Own enough draught (Subjective measure)	33	47	39	39
Short of draught (2-4 oxen)	26	29	28	27
Draughtless	39	25	23	31

Source: Bratton (1984), Elliot (1989).

million cattle died because veterinary services were not fully functional. Then during the drought of 1982-84 it was not possible to increase herds and therefore the draught power shortage continued.

Using cattle per cultivated hectare as an index of draught power availability, Stubbs (1977) found that this index decreased from 1.7 to 1.5 between 1961-62 and 1976-77 due to increased cultivated area rather than the cattle numbers. Using figures provided by AGRITEX it could be shown that by 1985 this ratio had further decreased to 1.4. Converting this figure to a team of draught oxen per cultivated hectare, and using four oxen to a team and about 30% oxen in a herd, Shumba (1984) estimated that there is 1 team/10 ha. The average size of each farm is 3 ha (arable land). The draught power shortage for field operations is about 65% in the communal areas.

Reducing the Draught Power Shortage

A. Minimise draught energy and time requirements per arable hectare per year

1. Conservation Tillage Systems
   - Select operation to minimise draught energy required
     - Minimise draught force required by the operation
     - Minimise distance force exerted/ha
   - Select operation to minimise time required/ha
   - Minimise frequency of operation
2. Implements
   - Minimise draught force requirements for given operation
   - Minimise time required for given operation
     - Increase working rate by increasing working width
     - Increase number of operations in one pass

B. Maximise Draught Power Availability

1. Increase draught power available from existing animals
   - Improve nutrition
     - Maintenance feeding during winter
     - Supplementary feeding during draught work
     - Improve pasture/fodder
   - Improve time of use
     - Seasonal: primary tillage at end of season
     - Daily: cooler part of day plus breaks

- Improve animal husbandry
  - Health
  - Selection of draught animals
- Improve handling and training
  - Training of handlers
  - Training of animals
- Improve yokes
- Match animals to power requirements
  - Single animals for low draught requirements

2. Improve draught power characteristics of herd
   - Improve nutrition
     - Improve pasture/fodder
     - Selective breeding
3. Maximise number of draught animals
   - Maximise herd size
     - Maximise carrying capacity of land
   - Increase proportion of draught animals in herd
4. Orientate social attitudes to greater use of draught animals
   - Facilitate draught animal hire schemes

The foregoing section is based on Elliot (1989).

Training Facilities

Animal training was started under the Engineering Branch of Conex in 1966. Research in agricultural engineering was consolidated in 1968 with the formation of what is now the Institute of Agricultural Engineering (IAE) under the Department of Agricultural, Technical and Extension Services (AGRITEX). This institute is now responsible for research, testing, development, training and extension in agricultural engineering.

Intensive training programs in draught animal power are run by the IAE mainly for in-service training of AGRITEX field staff but also for technical staff (multiplicators) from other organisations and countries. Assistance in this field has been received from Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) within the Zimbabwean-German cooperation.

Since 1985 the IAE has offered five 1-week courses in: Selection, care and training of draught cattle; Ploughing with draught cattle; Crop establishment; Crop maintenance; and Crop harvesting and transport.

Selection of Cattle

In Zimbabwe, selection is the procedure of choosing those cattle which have the potential to match the description of good draught animals when trained and fully grown. Selection takes place in two stages: (1) elimination of unsuitable animals, and (2) judging, if necessary, to obtain the most suitable animals from those considered suitable (usually oxen).

For Zimbabwe's conditions a good draught animal must be:

- of local breed or crossbreed, such as Mashona, Nkoni, Tuli or Afrikaner. These breeds of cattle are resistant to heat and some local diseases;
- healthy, which shows in balanced walking, good hearing, breathing, eating and appetite;
- of correct age and weight, that is between 18 and 30 months and 200–300 kg at selection. When fully grown the selected animal should weigh at least 500 kg;
- of good conformation, that is well-built with correct legs, neck, back, chest, shoulders and hooves;
- even-tempered, that is docile, alert and responsive.

Training Principles

To achieve successful adoption of training by the cattle after selection, the following training principles and training steps have been applied in Zimbabwe for more than 20 years.

- the trainer's approach: must be calm, firm, patient and consistent;
- Routine and repetition: training steps must be strictly followed by the same trainer in order to train the cattle in new behaviours. Animals learn by this process of routine and repetition;
- Rewards: reinforce correct behaviour and encourage positive actions and effort during training. Rewards can be food rewards or short breaks during work;
- Spoken commands: should be few in number, simple words and in one language;
- Training aids: should be used to achieve a training objective, then must be discarded when the desired behaviour has been achieved;
- Completion of a training step: each training step must be completed (behavioural objective achieved) before proceeding to the next step.

Training Program

The training program for cattle is divided into four training steps, which follow each other in a given order. Each training step deals with particular new commands and behaviours to be learned and mastered by the animal.

The steps are as follows:

— *Step One: Rieming and Walking* during which the objective is to calm the untrained animal and reduce the distance between the animal and the trainer. This is done in the kraal using a long riem and stick as training aids. Duration: 2–3 days.
Objective for the trainer is to become friendly with the animal and to achieve this by doing the following: riem the animal; walk and stop the animal; write its name on its belly; pet the untrained animal; remove the riem from the untrained animal.

— *Step Two: Harnessing and Walking* during which the trainer introduces the untrained cattle (oxen) to draught cattle harness, and walks the team in span outside the kraal, until the pair is able to respond to the commands correctly. Duration: 7–10 days.
Objectives for the trainer are as follows: to fit draught cattle harness on the untrained animals and then to remove the harness while they are outside the kraal; to make the harnessed animals walk, stop, turn right and turn left under the trainer's control.

— *Step Three: Pulling Loads* The potential draught oxen are accustomed to their trainer at this stage of training. The trainer must now help the cattle to develop their muscles and stamina, and train them to pull loads (logs) of various weights, starting with the lightest, on different surfaces. Duration: 2–14 days.
Objectives for the trainer are to develop the muscles and stamina of the draught animals being trained by pulling a heavy load for 2 hours a day at normal walking speed with only short breaks.

— *Step Four: Pulling Implements* After at least 4 weeks of training, depending on the abilities of the animals and the control achieved by the trainer, actual field work with implements can be introduced. Retraining is advisable if, during the season, the new draught animals have not done any draught work for a few weeks. After two full cropping seasons the trained draught cattle can do all draught jobs controlled by only one person. Duration: 21–30 days.
Objectives for the trainer are to complete the training so that the cattle will pull all farm implements such as ploughs, harrows, cultivators, planters and ox-carts correctly according to specific requirements.

Health Requirements of Draught Cattle

The general health care of draught cattle is the same as for other cattle in the herd. Daily health checks, prevention of injury, vaccinations, dosing and tick control (dipping) are carried out as normal, because good health is essential if the draught cattle are to work regularly. Any serious conditions, whether injury or disease, are reported to a veterinarian.

Mechanisation Specialists

Zimbabwe has a good extension service, but the lack of mechanisation specialists in the field limits extension of knowledge. The general extension workers receive in-service training in animal draught use during five 1-week courses, but these courses are on a particular topic and do not bring them up to a highly professional level. Therefore they need additional training and advice from specialists. The latter should also provide feedback on problems and requirements from the farmers to the researchers.

Conclusions

Draught animals will continue in the future to be a major source of farm power in the communal farming sector in Zimbabwe. Schemes for training extension workers and instructors are clearly needed. Draught animals are part of a highly adaptable, integrated smallholder farming system where they have a variety of different technical, economic and social functions that reduce drudgery in village communities and improve their operations.

It should be stressed that animal power in no way competes with increased use of tractors. Each is used where appropriate and sometimes even together. In many cases, draught animal power will open the way for the use of tractors in the medium and long term. In any event it is an effective way to help the farmer to increase sustainable crop production and improve living conditions in the communal farming areas in Zimbabwe.

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Alternative Applications of Animal Power

Paul Starkey*, Abiye Astatke and Michael R. Goe****

Abstract

Animals are mainly employed for tillage and transport. Alternative technologies are highly specialised or require large-scale resources. Animal-drawn scoops can level fields, make roads and construct ponds. In Ethiopia, communities excavating 9000 m^3 ponds extracted 7.0 m^3 of soil per ox-pair day. Problems were organisational and social, not technical. Ethiopian farmers are evaluating modified *maresha* ards for constructing terraces and broad-beds. Motor pumps are increasingly replacing traditional irrigation wheels. In the Sahel, some prototype animal-powered water-extraction systems have offered social benefits. Traditional mills requiring slow speed but high torque are well-suited to animal power. Modern machinery requiring high speeds is not. Prototype treadmills, sweeps and gear systems are often inefficient, cumbersome and expensive. They are slower and less convenient than motorised alternatives. Prototype donkey-pulled mills in Senegal produce reasonable flour and save women drudgery. Animal-drawn groundnut- and potato-lifters are well proven, but mowers and cereal harvesters are rare due to high cost, complexity, high power requirements and vulnerability to damage. Prototype weeder-rollers are heavy and expensive but effectively control plantation undergrowth. Horses, mules and oxen are increasingly employed for logging. The technologies discussed offer potential for diversified employment of animals but caution and pragmatism are advocated.

Introduction

THROUGHOUT the world, animal power is mainly employed for soil tillage, crop cultivation and transport. This paper deals with some other applications of animal power. Most of these alternative operations are relatively uncommon, particularly in sub-Saharan Africa. The restricted use of these alternative technologies by individual small farmers may be because:

- the application is highly specialised;
- the technology is quite new and has not yet had a chance to diffuse; and
- the equipment is economically, socially or technically inappropriate for small farms.

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In recent years there have been several calls for research on diversified applications of animal power (FAO 1984; ILCA 1988a; Starkey and Ndiamé 1988; Starkey et al. 1989). In some circumstances it has been felt that animals could provide a relatively cheap and ecologically appropriate source of power for specialised rural industries such as forestry. In other cases it has been argued that the ownership of draught animals by small farmers could be better justified if the animals could be used for more operations each year. Increased annual use should spread the overhead costs of owning draught animals over more days, thereby decreasing average daily costs. Increased use should also lead to higher standards of animal training.

This review of the subject will concentrate on African experiences, although references will be made to work in other continents. Much of the information contained here is based on research for the book 'Harnessing and implements for animal traction' due to be published by Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) later this year (Starkey 1989). Staff of the International Livestock Centre for Africa (ILCA) contributed the material relating to experience in Ethiopia.

Animal-Drawn Scoops

Animal-drawn scoops for levelling fields or for 'water-harvesting' have been employed in Africa and elsewhere for many years (Hopfen 1960). In Egypt wooden scoops of traditional designs are used to level fields prior to irrigation. Following tillage with an ard plough, soil is scraped up from the higher parts of the field and deposited in the lower areas. Further levelling can be achieved by simple ride-on boards or logs. Such levelling boards are widely used in Egypt and parts of Asia, particularly where fields have to be extremely level to allow maximum benefit to be gained from scarce irrigation water.

In the past century, there have been many examples of animal-drawn steel scoops being used in Africa and Asia for land levelling and road construction. Various designs have been employed, but essentially the scoops are made from sheet steel to which are attached two wooden steering handles and a movable U-shaped steel drawbar. Unless the soil is very light and sandy, it has to be first loosened with a plough or cultivation tines. In arid areas of Kenya, donkeys have been used to pull scoops in order to collect water in designated valley areas, so concentrating the scarce water in farmers' fields and minimising runoff in a technique known as water-harvesting (ITDG 1985).

Research on Pond Excavation in Ethiopia

In Ethiopia ILCA, in cooperation with several local organisations, has been investigating the use of animal-drawn metal scoops for excavating new ponds and for desilting old ponds. The aim has been to supplement dry season water supplies for both humans and livestock.

The basic scoop design employed in the initial trials was similar to the traditional Dutch horse-drawn 'mouldbaert' and the British 18th century 'levelling box' (Branford 1976). These European implements had been designed to be drawn by large animals, and so ILCA developed a smaller version with a capacity of 0.15 m^3 that could be pulled by a pair of Ethiopian zebu oxen. Initial testing of the technology began in 1983, with the excavation of a

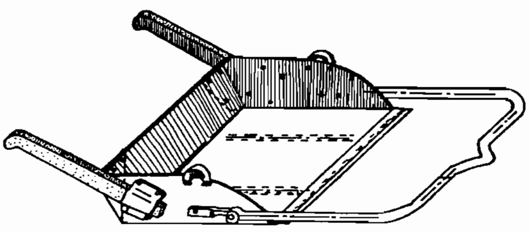

Fig. 1. Animal-drawn scoop (after Pathak 1984).

7000 m^3 pond on ILCA's research station in Debre Berhan, 120 km northeast of Addis Ababa (Abiye Astatke 1984).

Pond construction requires the use of two simple implements: the traditional ard (***maresha***) and the animal-drawn scoop. The maresha is first used to break up the soil surface where the pond is to be excavated. The loosened material is removed with the scoop to a dumping site at one end of the pond. The maresha is then used again to break up the subsoil which is in turn removed by the scoop. This pattern of tillage and scooping continues until the pond is completed. The total amount of time spent scooping depends on the size and condition of the animals and the friability and moisture content of the soil. At Debre Berhan, approximately 10 hours of tillage were required for each 100 m^3 of soil removed (Abiye Astatke et al. 1986). The average draught power developed by a pair of local zebu oxen pulling a full scoop was 0.92 kW, which falls within the upper range of power needed for the first pass with the maresha (Abiye Astatke 1984). Subseqently the Ethiopian Ministry of Agriculture (MOA) redesigned the scoop to reduce power requirements. The new models are about 15% smaller than the first prototypes and have two metal skids on the bottom to reduce friction. The scoops are robust and if the wooden handles break they can be easily repaired by the farmers themselves (Fig. 1).

Using animal-drawn scoops, two ponds of 9500 m^3 and 8700 m^3 capacity were constructed in 1985 by two Ethiopian Peasant Associations. Farmers worked about 75 days and employed 1350 ox-pair days. On average oxen worked about 6 hours a day, with three pairs breaking up the ground and 14 pairs engaged in excavations with scoops. Net excavation rates (including both ploughing and scooping) were about 6.8 m^3 of soil per oxen pair per day (Anderson and Abiye Astatke 1985). Pairs of oxen used for desilting existing ponds were able to excavate 13 m^3 of silt per 5-hour working day (Abiye Haile Selassie and Cossins 1985).

Problems Encountered in Pond Construction

Approximately 1300 scoops have been distributed throughout the 14 provinces of Ethiopia. About 12 ponds have been excavated in western Ethiopia by farmers under the supervision of the MOA. The major problems experienced by the Ethiopian Peasant Associations in constructing ponds have been organisational. MOA lacks the resources and personnel to provide all locations with technical guidance, yet the frequency with which individual farmers bring their animals to work must be accurately planned to ensure that the ponds are completed on time. Failure to finish the excavation before the main rains creates major difficulties the following year, when standing water restricts the employment of oxen for subsequent excavation (Anderson and Abiye Astatke 1985).

Although the scoops are simple, they are expensive relative to the incomes of individual farmers. Individual farmers cannot excavate ponds alone and scoops have therefore been acquired by groups of farmers. This requires considerable cooperation within communities, as does the planning, siting and construction of large ponds. Social problems may arise. For example while Borana farmers in southern Ethiopia happily use their oxen to cultivate their individual plots, some are reluctant to use their animals for 'community efforts' that benefit everyone, even those who do not contribute labour. In eastern parts of the country the presence of 'food for work' aid programs has reduced interest in community pond-construction, since this gives no immediate rewards for the work.

Other Land Formation Equipment

A combination of conventional mouldboard ploughs, ridgers, harrows and levellers can be used for terrace formation, bund-formation and other types of land shaping for soil and water conservation. Research by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and ILCA in Ethiopia has indicated that large flat ridges (broad-beds) can greatly improve the drainage of heavy black soils (Vertisols), providing higher and/or more reliable yields in on-farm trials. ICRISAT developed systems of broad-bed cultivation using wheeled toolcarriers (Bansal and Srivastava 1981; Bansal and Thierstein 1982; ICRISAT 1983). However, although experimental results were encouraging (Ryan and von Oppen 1983), farmer adoption was minimal (Starkey 1988a). In Ethiopia, ILCA briefly evaluated wheeled toolcarriers but decided it would be more appropriate to modify existing local implements for land-forming operations. Jutzi et al. (1988) described the development of modified maresha ards in Ethiopia for use in terrace construction and broad-bed formation. Initially two ards were permanently joined to construct a broad-bed maker. This resulted in an implement that was effective but difficult to transport. Furthermore, the ards used to produce the broad-bed maker could not then be employed for normal ploughing. A new design was therefore developed in which two ards are only temporarily joined to form a single implement (ILCA 1988b) (Fig. 2). Simple wooden or steel mouldboards attached to the ards facilitate the formation of bunds and broad-beds. The work, which is being carried out by ILCA, the Ethiopian MOA, some nongovernmental organisations and local farmers, is still at an early stage of 'on-farm verification.' Initial agronomic results suggest that even with minimal inputs, the broad-bed and furrow technique provides more reliable harvests than traditional systems.

The use of a single modified maresha ard for terrace formation is at a similar stage of research. A steel or wooden mouldboard-shaped reversible wing is attached to the ard in place of the traditional two flat soles. This single 'terracing plough' has a power requirement of slightly less than the traditional ard. Trials have shown that level terraces 4 m wide can be established on an 8% slope by three passes of the plough. This corresponds to 650 m^2 of level terrace constructed per oxen pair working 7 hours/day. Initial 'on-farm verification' trials gave cause for optimism concerning its technical performance (Jutzi et al. 1988), but farmers have yet to adopt the technology on any significant scale.

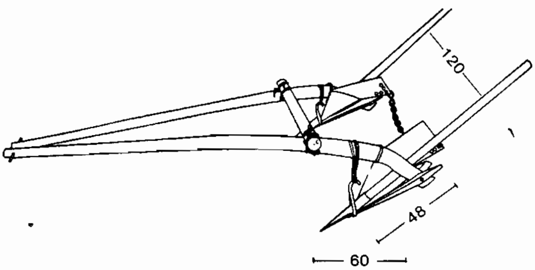

Fig. 2. Broad-bed maker made from two *maresha* ards.

Water-Raising Equipment

Traditional designs of animal-powered water wheels and other devices that provide relatively continuous delivery of irrigation water have been employed in North Africa and Asia for centuries (Löwe 1983, 1986a, b; Kennedy and Rogers 1985; Inter Tropiques 1985). Such systems make use of available materials and local energy sources, and can be made and maintained by local artisans. Among the well proven designs are the 'Persian wheel' and the Egyptian 'sakia.' The Persian wheel comprises a continuous loop of containers that scoop into the water, rise up, and empty out the water just after reaching the top of the wheel. The loop of pots can be quite long, so extraction from depths of 5–20 m is possible. For raising water to irrigation ditches from shallow wells the sakia is more efficient. This is because, unlike many other irrigation devices, water is not 'over-lifted.' Water is scooped up in a series of spirals, and discharged into the irrigation ditch from the central hub of the wheel. The distance water can be lifted is limited by the radius of the wheel, and is generally less than 2 m. This limits the use of sakias to quite specific conditions such as flat areas close to rivers, lakes or irrigation channels or other areas with a reliably high water table. The output of such sakias can be as high as 100 m^3/hour with a 2.5 m lift, and in Egypt one sakia commonly irrigates 6–10 ha of crops (Löwe 1983).

In some countries, including India, Pakistan and Egypt, electric or diesel pumpsets are quite rapidly replacing the traditional animal-powered technologies, often with the encouragement of government agencies. Nevertheless 'improved' prototype variations of traditional designs are still being produced (Kennedy and Rogers 1985; Tainsh and Bursey 1985; Baqui 1986).

In most of sub-Saharan Africa, animal-powered water-raising systems are absent or rare, but in several countries there have been serious problems in affording or maintaining high technology irrigation schemes using diesel or electric pumps. Suggestions have therefore been made that animal-powered systems could provide an appropriate solution, particularly as animal power can be one of the cheapest methods of raising water at low lifts. While this is a sensible option to consider, it is one that needs to be approached with caution. Even well-proven designs can be expensive to install and require maintenance (Löwe 1986b).

For domestic requirements, for providing water for animals and for small vegetable gardens, the raising of water from wells using animals to pull on ropes is a well-proven and quite simple technology. Such a system can be used with wells of any depth, including very deep wells for which pumping systems can be difficult. In Sahelian countries pairs of oxen may slowly walk away from a well pulling ropes 80–100 m long. When the container reaches the top, the animals turn and walk back in order to start the working part of the cycle again. Such a system is relatively slow, but it does allow essential water to be raised. In a traditional system known as a 'Delou' (or 'mote' in India) the pulling of the water container is made more efficient by making the animal(s) walk down a slope (Kennedy and Rogers 1985; Löwe 1986a). The need for the animals to walk to and fro is reduced in the 'Guéroult' version of the Delou developed by ISRA (Institut Sénégalais de Recherches Agricoles) and ENDA (Environment and Development in the Third World) in Senegal (Goubert 1982; Jacobi and Löwe 1984a, b; Deshayes 1988). This has ropes or wires mounted above the animals, so that they can walk in a large oval, continuing to supply useful energy on the return journey as well as the outward one. Extraction rates with a Guéroult can be 3–5 m^3/hour at 40 m, dropping to 1.5–2.5 m^3/hour at 80 m. In circular motes or 'Stoney's mote,' as used in Sri Lanka, one or more animals walk in a circular path, and a beam attached to overhead ropes or wires acts as a crank, converting the circular movement into the vertical lift and fall of two water containers (Löwe 1986a) (Fig. 3). A recent adaptation of this principle is seen in the 'Manège Sahores' developed in Senegal. An animal (usually a donkey) pulls a beam round in a circular path causing an overhead, counterbalanced rope to operate a simple piston pump. Extraction rates can be 6 m^3/hour at 6 m dropping to 1.8 m^3/hour at 20 m (Jacobi and Löwe 1984a).

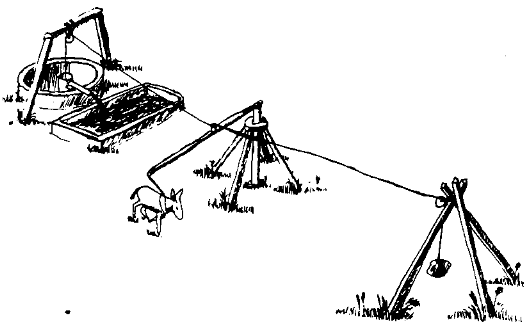

Fig. 3. A 'Sahores' mote (from Löwe 1986a).

Animal power has been used to drive adaptations of commercially available pumps. In one test in Botswana eight donkeys pumped 5.3 m^3 in an hour over a head of 38 m using a British 'Monopump' (Maseng and Jacobs 1985). Using a commercial pump and a multipurpose gear, two small oxen were capable of pumping 2 m^3/hour through a head of 16 m in Sierra Leone (Koroma and Boie 1988). In India, two heavy water buffaloes were reported to be capable of pumping 20 m^3/hour through an 8 m lift using a Danish 'Bünger' pump (Burton 1987).

Examples of prototype animal-powered water-raising systems are many, but examples of recent, successful introduction are quite few. Even in Senegal where some village systems have been in use for over 10 years, overall numbers are still very low. Local farm produce prices in rural areas are seldom sufficient to economically justify the investment in irrigation installations. For domestic purposes water-raising systems may improve the quality-of-life of people, but not alter their incomes. While one water-raising unit can serve a small village, this requires considerable cooperation for it is impracticable for farmers to bring their own animal to draw water. Water-raising systems may alter traditional patterns of labour partition between the different genders, ages and social groups (Jacobi 1985). In conclusion, animal-powered water-raising is a specialised technology with complex socioeconomic interactions and there is much to be gained from the careful study of previous experiences.

Animal-Powered Gears and Postharvest Operations

For centuries animal power has been usefully employed in various ways for crop processing. Some cereal crops can be threshed without any special equipment, merely by the trampling of animals, and this is the case in Ethiopia. However, basic threshing can be more efficient with the use of animal-pulled threshers similar in appearance to rotary puddlers or disk harrowers; such implements can be found in several north African countries including Egypt.

Simple traditional mills requiring slow speed but high torque can be turned by animals. In northeast Africa camels are employed to turn simple mills based on a large wooden pestle and mortar designed to press oil-seeds such as sesame. Animal-powered sugarcane crushers, which also require only low speeds and high torque, are widely used in parts of Asia and are commercially available in India (ITP 1985). They were adopted to a limited extent in Madagascar (CEEMAT 1971) and have been commercially produced in Kenya (ITP 1985).

Animals can also be used to power a wide variety of more complex grinding mills and various types of crop processing machinery that require high speed rotation and relatively low torque. The mechanisms for harnessing the power of the animals sometimes involve treadmills, but more commonly they are based on long, animal-turned drives or sweeps. As the animal(s) walks round in circles, power is transmitted through a system of gears or belts to the output machine. A useful review of this subject was provided by Löwe (1986a), who discussed historical precedents and modern applications. Other publications giving details of long-standing designs of animal-powered systems include Partridge (1974), Major (1985) and CEEMAT (1971).

Complete purpose-built gear units were sold for many years in North America and Europe, and in recent years have been available in Pakistan (ITP 1985) and Poland (United Nations 1975). There continues to be interest in designing single- or multipurpose gear systems for use in developing countries. Many systems designed during the past 50 years have involved animals walking in circles around the differentials of axles from old vehicles which have provided the basis for the gearing system (Hopfen and Biesalski 1953; Hopfen 1960; Finn 1986; Mueller 1987; Roosenberg 1987). One unit recently developed by AFRC-Engineering, UK, was based on the gears of a cement mixer.

More recently the Development Technology Unit of the University of Warwick has taken a different approach to the development of animal-powered machines and has tried to develop animal-powered rope engines. In these the animal walks round a circle of rope, pulling a beam on which is a pulley. As the pulley runs round the rope, the rotational movement of the pulley is transmitted to a second rope, and so to the final output (Thomas 1989). Although these designs are still at an early prototype stage, a program of testing and evaluation in several countries in Africa and Asia is being planned.

In the early 1980s, the German Appropriate Technology Exchange (GATE) financed a project that involved installing animal-powered systems for raising water or grinding cereals in about 20 locations in West Africa (Busquets 1986). While some units were designed for specific applications (pumping or milling) one system was a multipurpose drive that could power a range of pumping, hulling and grinding equipment. The requirement to perform several different functions made the multipurpose unit the most expensive of the gear systems that were developed. One multipurpose unit is being evaluated in Sierra Leone where it pumps water for an animal-traction station and also dehulls rice. A prototype cassava grater is being developed for this gear system (Koroma and Boie 1988).

A completely different type of animal-powered equipment was also developed by the GATE project (Boie 1989). This is a single-purpose grinding mill that is mounted on a rotating beam. Power for the mill is supplied by a short chain driven from a ground wheel running on a low wall of 5–6 m diameter. The wheel rotates at about 10 times the rotational speed of the sweep as the animal walks round in circles (Bielenberg 1988). This is capable of grinding about 10–20 kg millet/hour. In one village in Senegal, the installed mill worked for about 6 hours/day, and women brought their own donkeys or horses to provide the power to grind their own millet (Busquets 1986). Although the mill was well accepted, it had some disadvantages; for example grain to be milled using animal power had to be very dry and the quality of the flour was not as good as that obtained by diesel-powered mills or by pounding. As the mill was communal, there were some social and organisational problems ensuring that people had access to the mill and an animal at a convenient time. However, the women felt that the mill saved them the considerable drudgery involved either in pounding or in travelling to the nearest power mill (Starkey and Faye 1988). While the grinding unit itself is not suitable for village manufacture, the gear mechanism and circular track can be made and installed by local artisans and several have been made in Senegal (Fig. 4) (ENDA 1986, 1987).

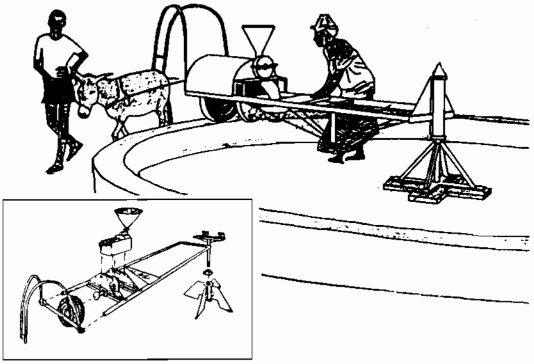

Fig. 4. Animal-powered cereal mill developed in Senegal (after ENDA 1986 and Bielenberg 1988).

Reasons for low adoption of animal-powered gear systems appear to be both technical and socioeconomic. Animals walk around gears and sweeps at a rate of about 2–3 revolutions per minute (r.p.m.), and yet many machines require axles rotating at 200–1000 r.p.m. or more. Thus very high gearing is necessary with inevitable frictional losses, and this makes animal-powered gear systems fairly inefficient. Low-friction gearing and bearing systems are usually expensive. Work animals are powerful and heavy and it has proved particularly difficult to devise efficient and low-cost gearing systems that are strong enough to withstand the very large, sudden and asymmetrical forces that even docile animals can apply to a gear system. Furthermore it is difficult to obtain output devices (mills, hullers, pumps, etc.) suitable for use with animal power, for most modern mass-produced machines have been designed for consistent, high rotational speeds. While it has proved technically possible to solve the problems in several prototypes, this has been costly, and some gear units are expensive to install.

Animal-powered gear systems were once widely operated in Europe and North America, and some units are still in use today. However, although the technology has been historically proven, most animal-powered systems were developed in the absence of realistic alternatives such as small stationary engines. Today small petrol and diesel engines are widely available (at a cost) and in rural areas in Africa small motors are increasingly being used and maintained for milling and transport. Small engines can often achieve in a few minutes the work that would take an animal (and its supervisor) several hours. In such circumstances farmers are unlikely to favour the animal-powered option unless it is **significantly** cheaper. It has already been noted that the installation costs of animal-powered gears are generally high. Although running costs of animal-powered systems may well be low, animal-energy is not 'free,' and the social costs/benefits of animal care and supervision have to be balanced against the convenience of using stationary motors. Both animal-powered gears and motorised alternatives are suited for use by many people and this may have important social implications for community cooperation or wealth disparities.

The relationships between price, convenience and efficiency of animal power and motor power are very different for slow-speed tillage operations and high-speed stationary applications. Historically and in recent years, some of the first operations to move from animal power to motorised power in Europe, North America, Asia and North Africa have been water pumps and grinding equipment (Binswanger 1984). Well-proven and long-accepted animal-powered machines already installed in villages have been abandoned and replaced by motorised alternatives. The installation of animal-powered gears into new villages necessitates considerable financial cost and training effort, at a time when small engine-powered alternatives are becoming increasingly available. There are few, if any, recent examples of animal-powered gear systems being adopted on a significant scale and it may be that prospects for the technology are limited.

Harvesting Equipment

Animal-drawn groundnut lifters and potato lifters are quite widely used, some being single-purpose tools, while others are attachments to simple multipurpose toolbars (ITP 1985; Herrandina 1987). Cassava is not well adapted to lifting with animal power since it is a woody and deep-rooted crop that is often harvested when the soil is hard. Yams are usually grown in areas where few draught animals are used. Trials have been undertaken in Côte d'Ivoire on growing small varieties of yams in ridges and lifting yams using animal power, but problems were experienced in combining effective crop cultivation practices, socially acceptable varieties and ease of lifting (Bigot et al. 1983).

Animal-powered equipment for harvesting cereals has been available for a long time. There are reports of 'Gallo-Roman' reaping machines which were animal-**pushed**, two-wheeled carts, with an adjustable comb and blade at the front. As the reaper was pushed through the grain field, the heads of the crop would be broken off, and fall into the cart, leaving much of the straw standing in the field. Since no examples of this technology remain in existence, it is difficult to judge the problems of clogging and wastage that would have occurred with such an implement (Gill 1977; Smith 1979). Derivatives of such designs were used in the UK in the 18th century but were considered only suited to flat areas where there was excess straw (Smith 1979). More complicated animal-**drawn** hay mowers, and reapers for small-strawed cereals, such as wheat and barley, were developed to a high degree in Europe and North America between about 1840 and 1930. They required both high draught power and reasonable speed, and so were generally used with stong horses rather than oxen (Binswanger 1984). During much of this time motorised harvesting was not a realistic option.

Some illustrations and details of horse-drawn harvesting machinery were provided by CEEMAT (1971), FAO/CEEMAT (1972) and Viebig (1982). Despite trials with such equipment on research stations in the tropics, there are few records of their use by small farmers. The main reasons for their lack of acceptability appear to be:

- their high cost, which is unlikely to be justified from the profits of one small farm;
- their complexity which necessitates considerable investment in training time;
- the fact that they are easily damaged by stumps and ground obstructions, making them only suitable for use in well-cleared land;
- their heavy weight and requirement for greater power and speed than is normally available from local oxen; and
- mowing is not a common operation in the tropics, where hay and silage production is difficult and where many pasture grasses and cereal crops have thick stems.

Those conditions that might be favourable for animal-drawn harvesting equipment (for example where farm income is high, technical knowledge is available and land is well cleared) may also be suitable for motorised harvesting equipment. Similarly those circumstances that might favour communal ownership or entrepreneurial hiring of animal-drawn harvesting equipment are also likely to favour motorised alternatives. This suggests that it will not be easy to transpose long-standing North American and European designs into the smallholder farming systems of Africa, Asia and Latin America.

There have been cases of animal-drawn carts or toolcarriers fitted with motorised mowers (Nolle 1986). These have had the advantage of requiring only a small motor for the mower as the power for transport was provided by the animals. To date the use of such equipment appears to have been confined to research stations where they may simplify experimental work on forage production.

Weeder Rollers

The use of large, heavy rollers fitted with cutting blades has been tested in projects in Tanzania and Cameroon (Becker 1987; IAD 1987). The rollers are 60–100 cm wide and are fitted with rotating steel frames supporting 6–12 knives. As the rollers are pulled along the rotating knives cut up grasses, small shrubs and surface trash leaving a mulch of chopped vegetation. Weight estimates for the implements range from a low 80 kg, reported for an eight-blade model in Cameroon (IAD 1987) to a high 450 kg for a 10-blade prototype in Tanzania (Becker 1987). In preliminary trials in Cameroon and Tanzania such rollers were used for clearing stover and weeds from fields prior to cultivation. Reported work rates are in the region of 5–6 team-days/ha (based on a 4–5-hour work day), while to achieve similar clearance would require 27–30 person-days. The weeders have been found particularly useful for weed suppression within orchards and under tree plantations and there are suggestions that the rollers might be usefully employed in alley cropping systems (Fig. 5).

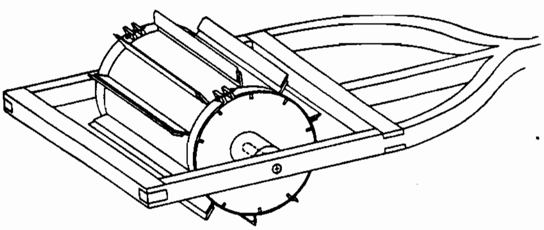

Fig. 5. Weeder roller (source: Becker 1987).

Reports of initial trials have expressed considerable optimism for the potential for these weeding rollers, which are to be further evaluated in Brazil, Cameroon, Ghana and Tanzania in conjunction with the University of Giessen in Germany. However, possible constraints to the adoption of weeder-rollers by small farmers include their expense, heavy weight, poor manoeuvrability within fields and difficulties in transporting the implements between different fields. In addition animals walking through the uncleared brush ahead of the roller may be subject to injuries caused by sharp lignified grass stalks. It may be that the weeder roller will prove to be more appropriate for clearing the undergrowth of orchards and plantations than for field-clearing operations on small farms.

Forestry

One specialised but effective use of animal power is for the extraction of timber from forests. Even where motorised alternatives are available, animal power may be both efficient and cost-effective for moving tree trunks from felling sites to forest roads. Indeed the use of horses and/or mules for logging in parts of Scandinavia, the United States and Europe appears to be increasingly attractive (Potter 1986; Chivers 1988; Vis 1989).In parts of Italy mules are employed to carry small logs on their backs using special pack saddles (Spinelli and Baldini 1987; Marquart 1988).

In Latin America techniques for using oxen for logging have been discussed in detail by Rodriguez (1984), Cordero (1985, 1986, 1988), Bonilla Mora (1986) and Mata Acuña (1987). The use of animals for pulling logs out of dense forest requires little specialised equipment other than comfortable harnessing, chains and hooks. Simple animal-drawn wheeled 'sulkies' can be employed to move large logs along tracks, and in well-cleared areas they can also be used to assist primary extraction. Sulkies are simple bars, frames or cranked axles which are supported by two wheels and pulled by means of a drawbar. Provided they have high clearance, wheeled toolcarriers can be used as sulkies, although such applications are rarely observed.

There has been some very well documented work on the use of mules for logging in southern Africa (Zaremba 1976). At the Usutu Pulp Company in Swaziland a mule and two labourers can extract and stack about 160 logs (20 t/day over distances of 80–150 m). In this case the logs are quite small being 1.5–2.4 m, with a maximum diameter of 45 cm. In the central and southern forest areas of Ethiopia teams of paired oxen or mules were used to haul 4.5–6 m logs, sometimes using sulkies (Logan 1946). Draught animals are no longer used for large-scale timber extraction in Ethiopia, but Goe (1987) reported that paired oxen or single horses, mules and donkeys are regularly used to transport firewood and to drag timber to building sites. Trials on the use of oxen for logging in northern Nigeria were described by Allen (1972). In Malawi pairs of oxen controlled by one person can extract 7 m^3 of larger logs a day over distances of 100–300 m, although rates of 5 m^3/day are more common. The animals used are often crossbreds of Malawi Zebu and larger exotic breeds, such as Friesian, although pure indigenous and pure exotic animals are also used (Cornelius and Broadley 1974; Solberg and Skaar 1987).

Conclusions

The technologies covered in this paper are either highly specialised or still at an early stage in the research-development-extension process. Many of the technologies are being strongly advocated by dedicated enthusiasts; however, as yet there seems little direct correlation between researcher optimism and farmer acceptance of the various implements, machines and installations discussed. This should not be a cause for pessimism or rejection of the technologies, for some of them appear to offer great potential if the technical, economic and social constraints can be overcome. Nevertheless because the technologies are very specialised or at a critical research stage, a cautious, pragmatic and realistic approach is recommended. People seriously contemplating work in one of these fields would do well both to thoroughly review the topics prior to any further initiatives, and to make contact with some of the organisations or individuals presently working in these fields. Additional references are to be found in the publications of Starkey (1988b; 1989) and Goe et al. (1989).

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Management of Draught Animals in Malaysian Oil Palm Estates

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Abstract

To overcome the shortage of estate labour, some oil palm estates have used buffaloes to assist the harvesters to transport the fruit bunches. Studies have indicated that the use of buffaloes in the estates has increased the harvesters' productivity and income by 31%. It also benefited the estates by reducing the total harvesters required by 24% and weeding costs by M$150–250/ha/year. The metabolisable energy (ME) intake of growing draught buffaloes grazing on native grasses was estimated between 807.05 and 958.82 $kJ/kg^{0.75}$ depending on the age of the buffaloes. These intake values exceeded the suggested requirements for maintenance and for draught. The energy balances agreed with the 0.35–0.55 kg/day liveweight gain recorded in the estate for growing draught buffaloes of different ages. These results thus suggest that buffaloes should be kept for dual purposes, providing draught and meat in the oil palm estates to maximise profit.

Introduction

THE oil palm industry in Malaysia has developed rapidly over the last two decades (Table 1). The rapid development in this labour-intensive agricultural sector has resulted in serious labour shortages in many estates. There were insufficient harvesters to harvest the ripened fruit bunches especially during the peak fruiting seasons, resulting in loss of revenue to the estates. The daily chores of harvesters include carrying the fruit bunches to specified locations where they are transported by trucks to the oil mills. Traditionally, this tedious job was done by the harvesters who had to carry the fruit bunches in two cane baskets on a carrying pole. Mini-tractors, bicycles, wheelbarrows and buffalo carts were introduced to the different estates to assist in transportation of the fruit bunches.

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This paper reviews information currently available, and wherever possible supported by research data, on the use of buffaloes for transportation in the oil palm estates in Malaysia.

Ownership and Training of Buffalo

Male swamp buffaloes 1.5–2 years old, weighing approximately 200 kg, are suitable to be trained for work in the oil palm estates. In almost all cases, the estate concerned buys the buffaloes and distributes them to the harvesters. Each harvester in return is required to repay the costs of his buffalo by monthly instalments over a period of 3–4 years. He is also required to train, feed and take care of his own buffalo.

Before the actual training begins the harvester must establish close personal contact with his buffalo. This should be done as soon as the buffalo arrives in the estate. The harvester must spend ample time in the first few days to handle, feed and bath his buffalo personally. Only after a close partnership with his buffalo has been developed can the harvester proceed to mount the cart on his buffalo. This must be done with great patience. The

Table 1. Planted area under oil palm in Peninsular Malaysia (1977-86).

Year	Hectares
1978	755525
1980	906590
1982	1084015
1984	1143522
1986	1328457
1988	1396269*

* estimated value.
Source: Anon. (1986).

time taken for the buffalo to accept the cart willingly varies from buffalo to buffalo and harvester to harvester. Generally a period of 1-2 months is needed for a buffalo to be sufficiently adapted to work. A well-trained buffalo understands and obeys his master's verbal commands to move forward, step backward or stop during the course of working.

Cart Construction and Load Capacity

The miniature buffalo cart is usually constructed of wooden planks and reinforced by iron frames at the edges (Fig. 1). When mounted with the cart the buffalo can manoeuvre easily along the undulating harvesters' paths at full load of approximately 0.5 t of fruit bunches. On a normal working day a buffalo hauls 4-5 cartloads which is equivalent to 2-2.5 t of harvest, while a harvester using the traditional cane baskets carries 1.5 t (Liang et al. 1984).

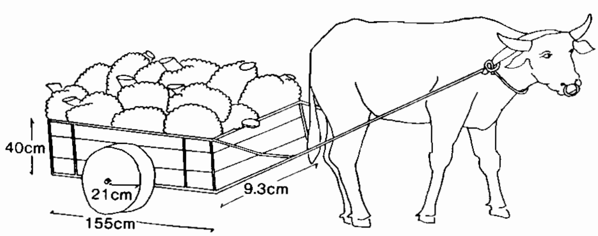

Fig. 1. Illustration of a growing swamp buffalo hauling a buffalo cart loaded with oil palm fruit bunches.

Management of Buffalo

Work starts early in the morning when the harvester and his buffalo arrive at the harvesting site allocated to them for the day. The buffalo is allowed to graze in the interrows of the palms while the harvester cuts the ripened fruit bunches. Collection and hauling of the fruits usually start about 2-3 hours later and last for another 2-3 hours. This chore is sometimes assisted by family members: children, women or old folks. In between periods of collection and hauling, the buffalo continues to graze along the harvesters' paths.

An average working day ends at around noon. During the peak fruiting seasons, harvesting and hauling resume again after a short break until late afternoon. At the end of the day, the buffalo is taken to nearby streams to drink and wallow. It is then tethered at specified grazing areas near the harvester's house until the next morning. Salt water or commercial mineral licks are usually the only supplemental feed given to the buffalo.

Nutritional Requirements

It was reported that the average daily gain (ADG) of 2-year-old draught buffaloes grazing only the native grasses available in the estate was 0.55 kg. The growth rate of these buffaloes declined slightly as they aged to 0.36 kg/day (Liang and Rahman 1985). These values were found to be comparable to those reported for swamp buffalo kept on research farms in Malaysia (Jainudeen et al. 1978; Liang et al. 1982). Supplementary feeding with cut grass or commercial cattle pallets during the night did not result in significant extra liveweight gain as compared to those which were allowed to graze only during the day (Liang and Rahman 1985).

In a recent study chromium oxide (Cr_2O_3) was used as fecal marker to estimate the dry matter (DM) intake of free grazing draught buffaloes of two age groups (growing, 250-350 kg, and near-mature, 420-450 kg). The results of this study are shown in Table 2. Average DM intake of 116.5 g/kg$^{0.75}$ and 98.06 g/kg$^{0.75}$ for the two age groups respectively was comparable to the 121 g/kg$^{0.75}$ reported by Bakrie et al. (1987).

The metabolisable energy (ME) intakes (calculated as DM intake $\times$ ME value of feed) estimated for the growing and near-mature buffaloes were well above the maintenance requirements for swamp buffalo (554 kJ/kg$^{0.75}$) suggested by Liang and Samiyah (1988). These values were equivalent to 1.73 $\times$ maintenance and 1.46 $\times$ maintenance respectively for the two age groups (Table 2).

Taking into account the energy required for work, i.e. 10 kJ/kg body weight/hour (Kearl 1982), and an additional hour of walking (2 km) within the plantation, consuming 2.09 J/kg body weight/m (Lawrence 1985), the energy balance for the growing and near-mature draught buffaloes was estimated as 345.5 and 188.8 kJ/kg$^{0.75}$, respectively (Table 3).

Table 2. Dry matter intake (DMI) and metabolisable energy intake (MEI) of draught buffaloes of different ages in oil palm estates.

Buffalo groups	Body weight (kg)	DMI (kg)	DMI/kg (%)	DMI/kg$^{0.75}$ (g)	MEI/kg$^{0.75}$ (kJ)	MEI/ME$_m$[a]
Growing						
1	250	7.64	3.06	121.52	1000.11	1.81
2	270	6.82	2.53	102.29	841.85	1.52
3	350	9.48	2.71	117.15	964.15	1.74
4	351	10.14	2.89	125.05	1029.16	1.86
Mean	305	8.52	2.80	116.50	958.82	1.73
Near-mature						
5	420	8.30	1.98	89.46	736.26	1.33
6	450	10.42	2.31	106.65	877.73	1.58
Mean	435	9.36	2.15	98.06	807.03	1.46
Overall	349	8.94	2.47	107.28	882.93	1.59

[a] ME maintenance (ME$_m$) = 554 kJ/kg$^{0.75}$.

Table 3. Energy intake, utilisation and balance of draught buffaloes in oil palm estates.

	ME (kJ/kg$^{0.75}$)				
Buffalo	Intake	Maintenance	Draught[a]	Walking[b]	Balance
Growing	958.8	554	41.9	17.4	345.5
Near-mature	807.0	554	45.7	18.5	188.8
Overall	882.9	554	43.8	18.0	267.2

[a] 3 hours/day.
[b] 2 km/day.

Table 4. Energy requirements for draught buffaloes in oil palm estates.

	Body weight (kg)			
	200	300	400	500
Maintenance (MJ ME/day)	29	40	50	59
Growth[a] (MJ ME/day)	18.4	13.8	10.8	5.4
Draught[b]: (MJ ME/day)				
1 hour	2.8	4.3	5.7	7.1
2 hours	4.8	7.3	9.7	12.1
3 hours	6.8	10.3	13.7	17.1
4 hours	8.8	12.3	17.7	22.1

[a] Expected gain of 400, 300, 200 and 100 g, respectively, for the different weight groups.
[b] Including 1 hour of additional walking.

Assuming that the energy requirements for weight gain were 46 kJ and 54 kJ ME/g gain, respectively, for the growing and near-mature groups (Kearl 1982), the expected liveweight gain for the two age groups estimated from the energy balance data was 549 and 333 g, respectively. These estimates were close to the 350–550 g gain/day reported earlier for draught buffaloes in the same plantation (Liang and Rahman 1985). These results thus suggested that the native grasses provide sufficient nutrients for growing draught buffaloes in the oil palm estate. Based on the results of this study together with earlier findings, the energy requirements for draught buffaloes hauling fruit bunches in oil palm plantations were proposed (Table 4).

Economic Advantages

The economic advantages of using draught buffalo to assist in the transportation of fruit bunches in the estates have been reported by different workers (Muirhead 1980; Liang et al. 1984). Although the use of draught buffaloes involved an increase in cost components (e.g. purchase of animals, construction of carts, etc.), the benefits outweighed the cost. The net profit/

hectare/year was estimated to be between M$57.08 and M$65.85 depending on the number of years the animals are kept (Liang et al. 1984).

The productivity and thus the income of the harvesters using the buffalo-assisted system were reported to increase by 30.7%. This was equivalent to a 23.5% decrease in labour requirements for the estate. At the same time the labour turnover of the estates also decreased, presumably due to better income for the harvesters. Costs of weeding, which usually take up a large portion of the total costs for maintenance of the estates, also reduced significantly. Although savings from costs of weeding varied from area to area, it was estimated that an average of M$150–250 were saved/hectare/year of the estate land (Liang et al. 1984).

The advantages attributed to the use of draught buffalo in the oil palm estates should be fully exploited. To achieve maximum return, the system should be based on producing dual-purpose animals, providing draught power while they are still growing and then slaughtering for meat when they have reached maturity.

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Section 7

Engineering Aspects of DAP

Animal-Drawn Implements: An Overview of Recent Research and Development

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Abstract

Recent research and development work on animal-drawn implements has included: on-station prototype design and development, on-farm farming systems research, broad technology reviews, experiments on implement–soil–crop interactions, design of technology for measuring implement performance, and development-orientated work assisting village blacksmiths. Some recent work on ard ploughs, ridge-tiers, animal-drawn seeders, weeders and multipurpose toolbars is briefly reviewed. Research lessons are drawn from animal-drawn wheeled toolcarriers. These proved effective on research stations and appear to be theoretically profitable, but few farmers have adopted them as multipurpose implements. The adoption by small farmers of 'improved' implements remains low, and greater understanding of the complex requirements of equipment in farming systems is needed. Implement researchers may not fully appreciate the constraints of resource-poor farmers, but animal-drawn implements must be appropriate to the prevailing environmental and socioeconomic conditions. Historically progress came from close farmer–blacksmith collaboration, and development resources are increasingly being channelled to blacksmith training and support. Research-development programs could usefully work with farmers and blacksmiths to try to combine researcher knowledge of technological options and global experiences with farming systems analyses and the skills and understanding of local artisans.

Introduction

SOME scientists seem to be of the opinion that there is no real research taking place on animal-drawn implements. There is, they claim, *only* development work. This view implies a very narrow definition of research and a gross underestimate of the significant amount of adaptive research involved in implement development. While there is a lot of truth in the idea that implement design is as much an art as it is a science, rigorous and objective research still has a key role to play in improving the design and utilisation of animal-drawn implements.

The broad spectrum of recent research and development work on animal-drawn implements can be divided into several general categories, although many are interactive and interrelated:

• *Classical on-station design and development of prototypes.* Recent examples have included the development by AFRC-Engineering and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) of the 'Nikart' wheeled toolcarrier from 1978 to 1986 (Kemp 1983; Thierstein and Bansal 1988), the development of modified ard ploughs in Bangladesh (Sarker and Barton 1987), Ethiopia (Jutzi et al. 1988) and Peru (Herrandina 1987), the development of a conical puddler by the International Rice Research Institute (IRRI 1986) and the creation of the 'Roliculteur' for tillage in semi-arid regions by the Centre d'Etudes et d'Expérimentation du Machinisme Agricole Tropical (CEEMAT) (LeThiec and Bordet 1989) as well as numerous other prototype implements developed by many different organisations.

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• *Farming systems research on-farm evaluation of implements.* Recent examples have included the evaluation of simple toolbars in Mali (DRSPR 1989; Mungroop 1989), planters in Botswana (Horspool 1986), modified ards in Ethiopia (ILCA 1988) and weeders in Tanzania (Loewen-Rudgers et al. 1989).

• *Survey work on implement usage.* Recent examples include studies on the utilisation of *maresha* ards in Ethiopia (Goe 1987) and assessments of the distribution and working life of implements in Mexico (Sims 1987), Senegal (Havard 1985; Bordet 1987; Fall 1989) and Tanzania (Lyimo 1987).

• *Review work on implement design and utilisation.* Recent examples have included reviews on animal-powered systems (Löwe 1986), adoption of animal traction in Africa (Pingali et al. 1987), wheeled toolcarriers (Starkey 1988) and the use of animal-drawn implements in West Africa (Bordet 1988; Bordet et al. 1988).

• *Experimental work to increase knowledge of implement-soil-crop interactions.* Recent tillage studies have taken place in Brazil (Duret et al. 1986), Burkina Faso (LeThiec and Bordet 1989), India (Awadhwal 1988), Mexico (Sims et al. 1987), Niger (Betker and Kutzbach 1989) and Senegal (Sene 1989).

• *Technological work on materials and on systems for measuring and evaluating implement performance.* Recent work in this area includes the development of data-logging instrumentation by AFRC-Engineering (O'Neill et al. 1987; Howell and Paice 1988; O'Neill and Kemp 1988; O'Neill et al. These Proceedings), the development of an ergometer by the Centre for Tropical Veterinary Medicine (CTVM) (Lawrence and Pearson 1985; Pearson et al. 1989; Sims and Aragón Ramírez 1989) and the comparison of different materials for animal-drawn tines by CEEMAT (LeThiec and Bordet 1989).

In addition to these research areas, there is more development-oriented work involving the testing of implements and assisting village blacksmiths and small manufacturers to produce and market implements, and modify them in the light of farmer needs. While this seldom involves fundamental research, it may have very important implications for research-development programs, and examples of case histories written for the benefit of researchers include Harouna and Imboden (1988), Gueguen (1989), Traoré (1989), and Boie (1989).

It should be stressed again that these broad areas of research are interdependent, and all contribute in their own way to increased knowledge and understanding of animal-drawn implements. Some of these topics of implement research are being covered in other papers at this workshop (Starkey et al. 1989; O'Neill et al. These Proceedings; Starkey These Proceedings). This paper will therefore review other areas of implement research, concentrating on drawing out apparent lessons from the experiences.

Ard Ploughs

Different types of ard have been in use for thousands of years and numerically it is the most important animal-drawn implement in the world. The ard development over the centuries and the different designs in use in different regions of the world have been well reviewed by Haudricourt and Delamarre (1955) and Hopfen (1969).

The main animal-drawn cultivation implement in use in Ethiopia is the *maresha* ard, of which around 3 million are in use. The *maresha* has recently been studied in detail by scientists of the International Livestock Centre for Africa (ILCA) (Gryseels et al. 1984; Goe 1987). Goe (1987) reported that under typical farm conditions in the Ethiopian Highlands a pair of indigenous oxen each weighing around 290 kg pulls the 5 cm *maresha* share at a depth of 9–15 cm, with the relatively high draught force of about 1.0 kN. During the first four cultivations, a tillage rate of about 210 m^2/hour can be achieved, representing 48 hours/ha for each cultivation. Experimental trials have suggested that overall cultivation times could be reduced by 50% through the use of mouldboard ploughs (Abiye Astatke and Matthews 1982, 1983, 1984). Nevertheless most attempts to introduce mouldboard ploughs at the smallholder level in Ethiopia have failed. Reasons for farmer rejection have included higher cost, heavier weight, limited durability and difficulties in obtaining spares and repair services from village artisans (Goe 1987).

Other research involving the fitting of wings or mouldboards to *maresha* ards to allow the formation of broad-bed and terraces has been described by Jutzi et al. (1988) and is discussed further in Starkey (These Proceedings). ILCA scientists have also modified the *maresha* ard for use with a single animal (ILCA 1983). This involved replacing the traditional long beam with a shorter beam and skid, that connected to a swingle tree and traces. To date farmer acceptance has been negligible. The various changes (ard, single animal, different yoke design and use of traces) have all been brought together in one package, and being statistically confounded, it is difficult to determine whether it was the whole package or specific elements that caused low uptake. One complaint cited by farmers was that the short-beam *maresha* pulled by flexible traces was less stable and more difficult to control than the normal ard (Abiye Astatke, pers. comm. 1989).

The use of ard ploughs on a large scale has persisted in Asia, Africa and Latin America despite the promotion and spread of mouldboard ploughs. Ards are clearly well adapted to many present-day farming systems. Their continued importance is well illustrated by the present situation in India. Western-style mouldboard ploughs of good quality have been manufactured in India for several decades and are widely available at reasonable prices. Nevertheless their uptake has been quite slow, and the number of ards in use (30–40 million) greatly outnumber mouldboard ploughs (Shanmugham 1982). Some recent and on-going research may eventually help to clarify what are the features of the ard that make it so popular. In contrast to traditional steel mouldboard ploughs, most ards have a single, symmetrical share set at a fixed angle to the ground, a long traction beam (as opposed to a flexible chain) and a single handle. Furthermore they use materials and construction techniques that allow fabrication by village artisans.

Research being undertaken by CEEMAT involves the use of single symmetrical, angled tines for tillage in semi-arid conditions. These have not been mounted on wooden beams (as is the case with ards), but onto steel beams or toolbars, as commonly used in sub-Saharan Africa. Initial research reports of field trials have been encouraging (LeThiec and Bordet 1989).

In Peru, research is being carried out on combining many of the design features of traditional ards with the concept of multipurpose toolbars that can accept different steel attachments to assist ridging, weeding, potato lifting and inversion ploughing. While most of the principles of use remain the same, the complexity of manufacture, assembly and adjustment of the ard have been increased significantly. This ard has been tested and marketed in Bolivia, Honduras and Peru (Núñez et al. 1986; Herrandina 1987), and is being field-tested in Ecuador, Mexico and Niger.

In 1974 the agricultural engineer Jean Nolle developed a multipurpose long-beamed toolbar in Nicaragua, by combining the principles of the local ard with the successful 'Houe Sine' toolbar. This implement was subsequently developed and marketed as the 'Kanol' (Nolle 1986). As it developed it lost all links with the ard except for the continued use of the long beam. It is a relatively sophisticated steel implement and a wide range of steel tools can be attached to it. In comparison to an ard it is (like other steel toolbars) complicated, expensive and difficult to manufacture. Although the Kanol has been tested in numerous countries, including Indonesia, it has never achieved the same popular success as the traditional ard or the Houe Sine.

Ridge-Tiers

Joining ridges to form a grid of mounds and hollows can assist in soil and water conservation particularly in those semi-arid regions that have 400–700 mm of annual rainfall. Large yield effects attributable to tier-ridging (made with hoes, animal-drawn implements or tractors) have been demonstrated on research stations. Several designs of animal-drawn ridge-tiers have been developed, but to date there seems little evidence of farmer adoption. Simple designs developed and tested in Nigeria in the 1960s (Stokes 1963: ITDG undated) and The Gambia in the 1970s (Matthews and Pullen 1974) scraped the furrows between ridges and had to be lifted every few metres over the accumulated soil to obtain the ridge-tier. This was hard work for the farmer and animals, and few farmers appeared convinced that the benefits justified the considerable effort involved. More recently two prototype animal-drawn ridge-tiers have been developed in Burkina Faso. One developed by ICRISAT researchers is based on a ridger with a large eccentric ground wheel that changes the working depth cyclically and so creates very gradual ties; the other developed by researchers from IITA and SAFGRAD has four blades arranged at right angles, and the operator trips the blade to allow it to rotate by 90°, so depositing the soil and forming a ridge (Wright and Rodriguez 1986). A similar design of ridge-tier has also been developed by CPATSA, EMBRAPA and CEEMAT in Brazil, as an option for the CEMAG Policultor wheeled toolcarrier (Duret et al. 1986). While researchers are optimistic about animal-drawn ridge-tiers, the implements have yet to pass the test of farmer adoption.

Seeders and Planters

Animal-drawn seeders have seldom had the same degree of success as have ploughs and cultivators.

Notable exceptions to this general rule include Senegal and Mali in West Africa where single-row seeders are common, and the wheat belt of northern India where multiple-row seed-drills are used. Seeding can often be done quickly and effectively by hand while mechanical sowing devices are usually expensive and often require ideal working conditions.

Rolling injection planters, such as those developed by IITA in Nigeria are based on the dibbling principle. These have recently been evaluated in Brazil (Schmitz 1989) and small numbers have been manufactured by the UPROMA factory in Togo. To date the uptake of such seeders has been minimal and reasons for this may be associated with the high cost of these implements and the problems experienced by farmers in obtaining consistent results under field conditions.

Animal-powered seed drilling can be achieved very simply by the traditional method of using a plough (ard or mouldboard) as a furrow opener and hand-metering by dropping the seeds into the furrow. If furrow depth is not constant there will be seed wastage due to uneven germination, but with such low capital outlay, this may be acceptable. The problem of accurately aiming the dropped seeds can be overcome by the provision of a plastic seed tube that drops the seed behind the plough. This elegantly simple design can be adapted into a two-, three- or four-row planter. The seeds are hand-metered into a small wooden bowl and pass down plastic tubes to simple furrow openers. A second bowl and series of tubes can be used to make the implement into a combined seeder and fertiliser distributor. Such seeders are commonly used in India, and have been adapted for use with wheeled toolcarriers (Thierstein and Bansal 1988). In Africa, a recent prototype developed in Sudan uses a similar principle (Wylam and Sallah-El Din 1989).

Precision seeders use a ground wheel to drive a mechanism that causes seeds to drop at predetermined spacings behind the furrow opener. The *Super Eco* type of seeder is probably the most successful in Africa to date, and this uses a sealed gear mechanism to drive interchangeable inclined seed plates suitable for crops such as maize, sorghum, millet, groundnuts, cowpeas and rice. Despite many attempts to encourage multi-row seeding using two or more precision seeder bodies, farmers in West Africa have shown a clear preference for single-row seeding. While a single-row seeder could be pulled speedily by a single horse, dual- and multirow seeders required extra draught, and were normally pulled more slowly by a pair of oxen. The slower speed reduced the potential for time saving, and farmers did not consider the benefits justified the increased cost and weight and reduced manoeuvrability of multirow seeding (Havard 1986; Bordet 1987).

Cultivation Tines

Cultivation tines may be used for primary land preparation, secondary cultivation (harrowing) and weeding. For weeding purposes large triangular sweeps may be used, which have a similar effect to an Indian blade harrow. More common are intermediate triangular *duckfoot* points which are about 150 mm wide. For primary tillage and harrowing, as well as some weeding operations, narrower 50 mm points with a greater attack angle are more usual. For primary tillage the soil failure pattern of each point is similar to that of a small ard plough, although the working width and depth are much smaller.

Cultivators are widely used in West Africa, and most are based on multipurpose frames to which tines (and sometimes extension bars) are clamped. Different designs have been based on simple longitudinal (*Arara; Pecotool*), T-shaped (*Houe Sine; Ciwara*), triangular (*Triangle*) or rectangular (*Ariana*) toolbars. In Asia various cultivating tools may be attached to long poles in a manner similar to that of the traditional ard ploughs. Such cultivators may be multipoint implements or 250–400 mm blade harrows.

Multirow cultivators that weed two or more interrows were widely used in Europe and North America. Multirow cultivators have been designed or evaluated in many countries in Africa and in recent years several have been based on wheeled toolcarriers or intermediate toolframes. Multirow cultivators have been shown to be effective on research stations, yet their adoption by farmers has been minimal. The problems centre on manoeuvrability and crop damage. While single-row weeders can be lifted easily by the operator in cases of field obstruction or temporarily converging crop-rows, multirow weeders are much more difficult to lift and manoeuvre. Consequently in the uneven fields of many peasant farms, crops are much more likely to be ripped out of the ground by a multirow cultivator than by a single-row weeder. However Roosenberg (1987) argued that crop damage could be reduced through the use of weeders that straddle the row, weeding only half of each of the two adjacent interrows. He argued that low adoption of weeders was associated with the fear of crop damage and that this is almost inevitable using weeders which are set to weed almost all (80%) of the interrow space. Variation in row spacing and operator error when having to judge implement proximity to two rows simultaneously are likely to bring the weeder into contact with the crops quite frequently. The row-straddling weeder would diminish this problem. Unfortunately it is difficult to design an efficient, low-cost, single-row over-the-row weeder. They tend to have high centres of gravity (associated with the clearance needed to avoid damage to growing crops) and the operator either has to straddle the crop or to control the implement from only one side. Such problems can be solved by wheeled ride-on implements, but these have the major disadvantages of higher cost and weight and reduced manoeuvrability. On-farm research and development with over-the-row weeders in Tanzania has not yet succeeded in identifying clear solutions to the crucial technical and economic constraints (Mkomwa 1989). The 'Strad' over-the-row rolling weeder developed and marketed in Nigeria proved technically effective in experimental prototypes (Kaul 1987; Gwani 1989). The Strad is a heavy walk-beside or ride-on two or four gang rolling cultivator. The rotating tines are effective for weeding crops grown on ridges, but the adoption of the Strad has been low, perhaps due to its high cost.

Simple Multipurpose Toolbars

Multipurpose toolbars have become quite widely used in West Africa in recent years. One of the most successful designs, the *Houe Sine*, was developed by the French designer Jean Nolle in Senegal in the late 1950s (Nolle 1986). This comprised a T-frame with depth wheel, onto which clamped a variety of cultivating implements, including duckfoot tines, groundnut lifters, ridgers/earthing-up bodies and ploughs. Heavier straight-beam toolbars such as the *Anglebar (Multibarra)*, *Arara* and *Pecotool* and their derivatives have been used in several countries in Africa and elsewhere but have not caught on to the same extent. These have tended to be promoted in regions where ploughing and/or ridging is important (such as cotton-growing zones), where the cultivation tines have often been of secondary importance. *Houes* have been particularly successful in the lighter-soiled, semi-arid regions where the plough body has often been one of the least-used attachments (Starkey 1989). In Burkina Faso and Togo the multipurpose *Triangle* cultivator is often used in conjunction with conventional ploughs and ridgers.

Heavier, rectangular toolframes such as the *Ariana* and its derivatives have been developed from Jean Nolle's *Houe Saloum*, designed in Senegal in the late 1950s. These intermediate toolframes generally have two depth wheels, one on either side of the frame which gives great stability. For single-row weeding one wheel can be used in a central, forward position. The rectangular design of toolframes provides more space for additional implements, and so provides a potentially greater working width. However it has been observed that the limiting factor on small farms is often animal draught power, so that additional implements cannot be easily pulled, and the additional working width is seldom used (Starkey 1989). Intermediate toolframes are about twice the weight and cost of simple toolbars and their weight makes them less easy to transport or manoeuvre. Although they have received much acclaim when evaluated on research stations, they have never been adopted on the scale of simple toolbars. For example in Senegal, where they have been available for 25 years, sales in the period 1958–80 were about 8500 which represents less than 3% of the 340 000 simple toolbars (*Houes*) sold in the same period (Havard 1985). A farming systems research project in southern Mali is currently working with farmers to evaluate the potential for intermediate toolframes for the richer and more progressive farmers in the region (DRSPR 1989).

Wheeled Toolcarriers

Since the 1985 ACIAR Draught Animal Power workshop, there has been a significant shift in thinking relating to animal-drawn wheeled toolcarriers. Wheeled toolcarriers are multipurpose implements that can be used for the basic tasks of ploughing, ridging, seeding, weeding and transport and for additional operations such as spraying. They are usually ride-on implements, and are often thought of as 'bullock-tractors.' Most wheeled toolcarriers comprise a steel chassis and drawbar mounted on two wheels, often with pneumatic car tyres. The chassis supports a toolbar which can be raised and lowered and to which can be clamped a wide range of implements. There is often an operator's seat, and most have a detachable cart body (Bansal and Thierstein 1982; ICRISAT 1985; Sims et al. 1985; Kemp 1987; Thierstein and Bansal 1988).

At least 50 designs of wheeled toolcarrier of varying degrees of complexity were developed in various countries from 1955 to 1987, and the history of wheeled toolcarrier development has recently been reviewed in detail by Starkey (1988). He concluded that while about 10 000 toolcarriers had been manufactured between 1956 and 1986, the number that were ever used by farmers as multipurpose implements for several years was negligible. The majority were either abandoned or used as expensive carts which, because of multipurpose design constraints, were actually less efficient than purpose-built carts. Wheeled toolcarriers have been rejected because of their high cost, heavy weight, lack of manoeuvrability, inconvenience in operation, complication of adjustment and difficulty in changing between modes. By combining many operations into one machine they have increased risk and reduced flexibility compared with a range of single-purpose implements. Their design has been a compromise between the many different requirements. In many cases for a similar (or lower) cost farmers could use single-purpose ploughs, seeders, multipurpose cultivators and carts to achieve similar (or better) results with greater convenience and with less risk.

Starkey (1988) argued that farmer rejection had been apparent since the early 1960s, yet as recently as 1986 most researchers and people working in aid agencies, international centres and national agricultural programs were under the impression that wheeled toolcarriers had been widely adopted in some countries.

These impressions derived from the circulation of numerous encouraging and highly optimistic reports. Many wheeled toolcarriers developed have been shown to be technically effective, providing excellent precision in operations under the optimal conditions of research stations. Most published reports derive from such experience. Published economic models have shown that the use of such implements is theoretically profitable, given many assumptions relating to farm size, land use, prices of inputs, crop yields, producer prices and above all the availability of credit (Binswanger 1980; Ryan and Sarin 1981; Sims et al. 1988). In contrast publications describing the actual problems experienced by farmers under conditions of environmental and economic reality are rare (Sims 1988).

Conclusions

It is apparent that in recent years a great deal of research has been undertaken in order to develop improved and technically effective animal draught implements. Further work is in progress. However the adoption by small farmers of 'improved' implements remains low, much to the disappointment of the people involved. It is clearly important to identify the causes of low uptake of apparently suitable implements. With this in mind, an increasing proportion of research on animal-drawn implements is now aimed at achieving a better understanding of the complex interactions within farming systems, and the very diverse technical, environmental and socioeconomic requirements of equipment.

A century ago, animal traction implements developed rapidly in Europe and North America. The research and development was undertaken primarily by farmers and local blacksmiths in response to local problems. The market for agricultural produce was buoyant as the economies industrialised, and input and output prices were seldom affected by subsidies.

In contrast the research discussed in this paper has been undertaken almost exclusively by staff of research institutions. Although such professional researchers may be very sympathetic to the target-group of resource-poor farmers, they usually differ significantly from farmers in their background, social position and aspirations. Consequently it has often proved extremely difficult for researchers to understand and appreciate the numerous technical, social and economic problems experienced by small farmers, and to ensure that their research programs address these constraints as well as personal professional goals.

The small farmers who are the intended beneficiaries of research have colossal economic problems. With the activities of governments often geared to low food prices, farm revenues in developing countries are usually low. Capital accumulation is very difficult, and capital tends to flow to urban centres. Thus even when implement innovations are technically appropriate, they are often unaffordable. Providing relatively small institutional loans to widely dispersed small farmers without collateral is administratively expensive and fraught with problems, including misappropriation.

In theory, small farmers could overcome many of their limitations by pooling resources and farming cooperatively. Specialisation and consolidation might economically justify innovative animal-drawn implements. However small farmer individualism has long allowed self-sufficiency and has been a protection against risk, and there are few examples in developing countries where implement development and diffusion have been maintained by farmer cooperatives.

In practice, there is little that research workers can do to alter the macroeconomic situation and it is clearly unrealistic to expect national economies and farming systems to adapt themselves to innovative designs produced by agricultural engineers. Implements have to be appropriate to the existing situations. It seems clear that designing prototypes from ivory towers has seldom proved successful. Faster progress in implement design, development and adoption is likely to come from closer collaboration between designers and end users. As noted above, in historical terms, collaboration between farmers and village artisans was crucial for implement progress, and for this reason some development organisations have started trying to assist such linkages, providing blacksmith training and support.

There will always be potential for inventors who can create completely new technical solutions and for researchers who can measure, understand and explain complex animal-implement-environment-farmer interactions. However most implement-related research will probably be much less glamorous. Much has been done in recent years to review technological options and to share experiences (both good and bad) between countries. This international networking is probably one of the most cost-effective ways of achieving progress, provided it is combined at a national level with location-specific farming-systems studies. In an ideal situation, information on crucial farm-level constraints and farmers' ideas for solutions should be considered in the light of experiences from other countries and regions. Local blacksmiths familiar with farm conditions might then be assisted to use traditional or modern technology to build on past experiences to solve local constraints. Such cooperation could well prove to be a particularly productive means of achieving developments in animal-drawn implements in the coming years.

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Influence of Design on the Draught Force Characteristics of Animal-Drawn Carts

J. Betker and H.D. Kutzbach*

Abstract

A systematic approach is made to describe the factors influencing the draught animal transport system; general considerations for design of carts are discussed. Results of experimental work are presented that show the influence of construction parameters (pneumatic tyres vs steel wheels, roller vs wooden bearings) on draught force requirements, and the influence of forces under different conditions (laterite, sandy road, field and loose sand). Rolling resistance for each factor combination was also determined. For solid tyres the positive effect of springs for the reduction of peaks in draught force was analysed.

Introduction

TRANSPORTING goods is a basic need for all farming operations. Transport facilities greatly influence the timing of field work (seeding, fertilising), and determine the economic success of a farming enterprise by opening access to local markets.

Farmers solve transport problems by different means, depending on economic and environmental conditions — e.g. in hilly regions transport may consist of human portering, in industrialised economies transport is mainly done by tractor, and in many parts of the world animal-drawn carts play an important role in the transport sector at the farm level.

The success of animal-drawn carts can be explained by analysing a characteristic of transport operations. On the farm level many of these operations are 'medium sized': they cover medium distances, using roads of 'medium' condition and carry loads of up to 100 kg. For these situations animal-drawn carts are better than human portering and motor vehicles.

Experiences in Africa show that the introduction of carts is very successful when changing from human labour to animal traction; there are approximately 150 000 carts in the three Sahelian countries Burkina Faso, Mali and Niger (Starkey 1988). Even when changing from animal traction to tractors, much of the transport will still be done by animals, so animal-drawn transport will continue to play an important role in many countries (Munzinger 1981).

To design appropriate and functional carts, more information is needed about the influence of construction parameters on draught force characteristics to improve their performance to meet the needs of farmers.

Design Considerations

The design of an animal-drawn cart has to meet a number of criteria that influence and/or determine the transport situation at the farm level; these factors can be external ones that describe the background situation of the farming system, and internal ones that directly characterise the transport situation at the farm level.

External factors influence general design considerations (choice of material, level of sophistication, etc.), and internal factors have to be taken into account for detailed design decisions. A detailed list allows for a first preevaluation of an adapted cart design (Tables 1 and 2).

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Table 1. External factors of DAP transport system.

Environment		Economy				Social	
		Income level	Manufacturing		Maintenance units		
Material	Topography		units	techniques		Tradition	User group
- wood - steel - bamboo	- flat - hilly - dry - wet	- peasant farmer - cash crop farmer	- black-smith - workshop - factory	- forging - soldering - welding	- farmer - black-smith - workshop	- local models - crafts-person's skills	- men - women - children

Table 2. Internal factors of DAP transport system.

Draught animals		Goods		Routes	
Species	Harnessing	Quality	Quantity	Condition	Distance
- oxen - donkey - horse - bullock - . . .	- single - pair - group	- solid - loose - liquid	- weight - volume	- path - field - unpaved road - paved road	- on-farm - farm–market - farm–town

Table 3. Principal components of animal-drawn carts.

Frame						Platform		
Configuration	Tyres	Bearings	Suspension	Brakes	Harnessing	Form	Installation	Purpose
- two-wheel - four-wheel	- wood - steel - pneumatic	- wood - cast iron - rollers	- none - springs - hydraulic	- none - direct - indirect	- central beam - double beam - evener + spreader bar	- open - closed	- fixed - tipping	- single-purpose - multi-purpose

A selection of the materials and the principal components can then be made (Table 3).

A Case Study from Niger

Objectives

In recent years considerable work has been done in the agricultural sector of Sahelian countries to introduce draught animal technology. This was most successful in the area of transport, where many on-farm and farm–market goods movements are performed by animal-drawn carts.

However, the number of carts remains low because their use is restricted to farmers with a relatively high income. Bringing down the costs of carts will make them accessible to a larger group of farmers.

In an experimental study the most expensive parts of the actual cart model (pneumatic tyres, roller bearings) were replaced by low-cost components (steel wheel, wooden bearing) to compare the technical performance (rolling resistance, course of draught force) of these construction alternatives under different surface conditions.

Using solid tyres on laterite roads results in high vibration of the cart that causes discomfort to both driver and animal. Springs were tested to determine the extent to which the vibration could be reduced.

Some general information is given in the older literature about draught force characteristics (e.g. Stroppel 1940), but few investigations have been done in recent years (Desphande and Ojha 1985; Mery Grez et al. 1987).

Methods and Materials

The cart used for the experiments consisted of a wooden platform, a metal frame and a central beam for the attachment of the draught animals (Fig. 1).

The pneumatic tyres normally used were compared to steel wheels with a diameter of d = 80 cm and a width of w = 60 mm (Table 4). These three models were tested under different surface conditions to simulate the various applications at the farm level: transport on laterite road to simulate farm–market transport, on sandy roads for farm–field transport. On-field and loose sand represent off-road conditions (Table 5).

The carts were pulled on test tracks of 4 × 50 m at a speed of v = 1 m/sec. They were fixed to a specially designed frame that was mounted on a car.

Signals of the two load cells and a velocity meter were recorded continuously on a data recorder. Data analysis was done by computer after converting the original analogue signals to digital values. The course of draught force is classified in histograms to calculate average values and standard deviation (equations 1 and 2):

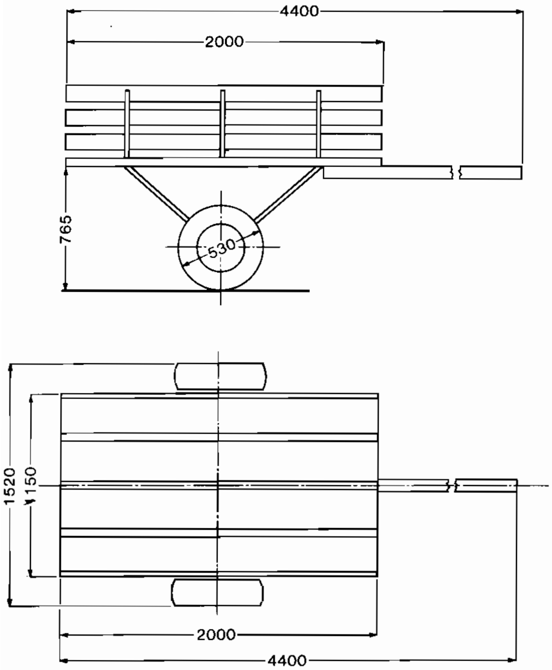

Fig. 1. Principal dimensions (in millimetres) of experimental cart.

$$F = \frac{1}{n} \sum_{i=1}^{128} n_i F_i \quad (1)$$

$$SD = \left[\frac{1}{n-1} \left[\sum_{i=1}^{128} n_i F_i - \frac{1}{n} \left(\sum_{i=1}^{128} n_i F_i \right)^2 \right] \right]^{0.5} \quad (2)$$

Forces acting in the system are the weight of cart and loaded goods (F_T), traction force due to rolling resistance of bearings (M_B) and wheel load (F_W) and the reacting forces (F_H and F_V) on the yoke (Fig. 2).

By measuring F_H and F_V separately the rolling resistance can be calculated by:

$$\mu_R = \frac{F_H}{F_T - F_V} \quad 100[\%] \quad (3)$$

This factor includes two components of rolling resistance: the wheel and the bearings. Analysing draught force requirements while using the same wheel with different bearings therefore allows for the calculation of the relative efficiency of this construction parameter.

Table 4. Configuration of experimental carts.

No.	Configuration	Specification
1	Pneumatic tyre and roller bearing	Tyre: 165 SR13 p = 1.5 bar, d = 530 mm, w = 16.5 mm Bearing: d = 25 mm greased
2	Steel wheel and roller bearing	Wheel: d = 700 mm, w = 60 mm, 22.5 kg Bearing: as (1)
3	Steel wheel and wooden bearing	Wheel: as (2) Bearing: d = 40 mm d = 70 mm, l = 80 mm greased oak

Table 5. Experimental surface conditions.

No.	Type	Characteristics
1	laterite	laterite road, even
2	sandy	sandy foot path
3	field	harvested millet field, scarified, on sandy soil
4	loose sand	foot path with loose sand up to a depth of d = 10 cm

The positive effect of springs was tested with steel wheels and wooden bearings on a laterite road. The springs, using spare parts from a pickup truck, were mounted between axle and chassis in packages of 4, 6 or 8 blades on each side. For these configurations the course of the vertical draught force was analysed.

Results

Analysis of data shows the highly significant influence of cart configuration on average values and distribution of draught force.

Horizontal draught force is a linear function of payload; e.g. on loose sand draught force requirements of steel wheels are more than double that for pneumatic tyres. Data also show the requirements for different bearings where rolling resistance of wooden bearings is 14% higher than for roller bearings (Fig. 3).

By comparing the rolling resistance of different wheel types the advantage of pneumatic tyres can be clearly seen. The average rolling resistance of steel wheels with roller or wooden bearings is 193% and 210%, respectively.

Draught force requirements also depend on road conditions; the average rolling resistance under off-road conditions is 6.3 times higher than on laterite roads and 2.3 times higher than on sandy roads (Fig. 4, Table 6).

Draught force experiments showed that pneumatic tyres dampen the peaks, whereas for solid tyres the course is relatively rough. This effect can be characterised by the SD of the draught force values where pneumatic tyres have significantly lower values than steel wheels (Fig. 5, Table 7).

The high peaks in draught force for solid tyres cause problems mainly on laterite roads. Experiments show that springs are able to partially absorb these peaks. While the course of the vertical force shows high maximum values for the unsuspended construction, the force for the spring-loaded configuration oscillates with a much lower amplitude (Fig. 6).

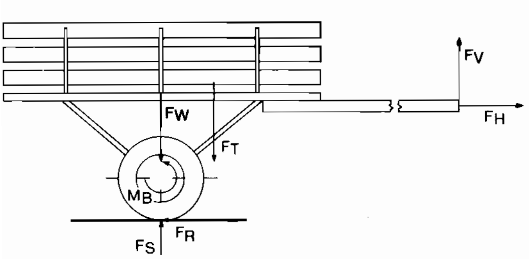

Fig. 2. Forces acting on a cart.

Statistical analysis of data shows a reduced standard deviation of force in the vertical plain for carts with springs under all levels of load (Table 8).

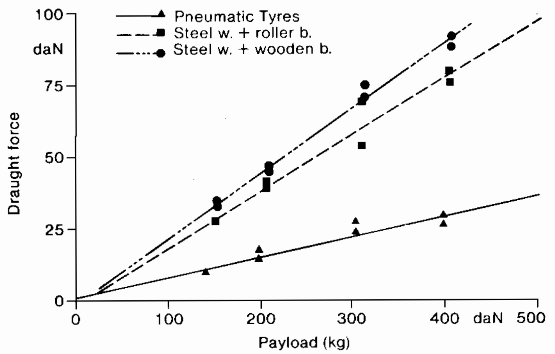

Fig. 3. Draught force on loose sand for different cart configurations at increasing payload.

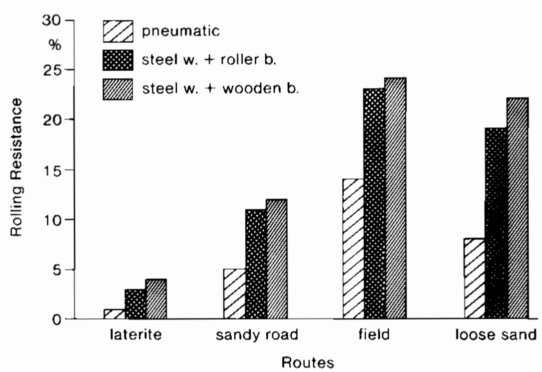

Fig. 4. Average rolling resistance for different cart configurations on various routes.

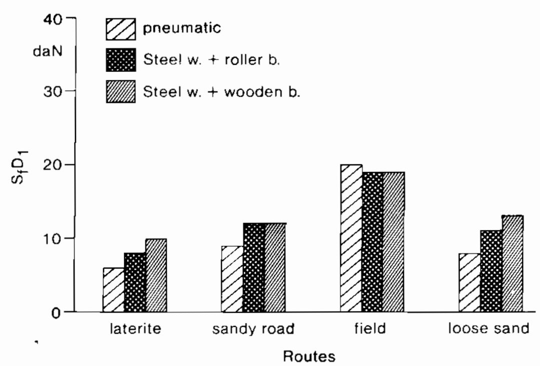

Fig. 5. Standard deviation (SD) of draught force for different cart configurations on various routes.

Table 6. Rolling resistance (%) for animal-drawn carts with different wheels and bearings under vaying road conditions.

Surface condition[a]	Configuration[a] 1	2	3	Mean
1	1.46	2.65	3.76	2.62
2	4.71	11.44	11.56	9.24
3	14.38	23.48	24.05	20.64
4	7.61	19.31	22.42	16.45
SE		± 1.20		± 0.74
Mean	6.69	12.96	14.10	
SE		± 0.74		

[a] See Tables 4 and 5.

Table 7. Standard deviation of force (daN) for animal-drawn carts with different wheels and bearings under varying road conditions.

Surface condition[a]	Configuration[a] 1	2	3	Mean
1	5.61	8.30	10.00	7.97
2	9.22	12.02	11.82	11.02
3	20.12	18.84	18.85	19.27
4	8.11	10.93	13.05	10.70
SE		± 0.52		± 0.90
Mean	10.68	12.33	13.30	
SE		± 0.90		

[a] See Tables 4 and 5.

Table 8. Standard deviation of force (daN) for animal-drawn carts without suspension on a laterite road for five levels of load.

Load	Configuration 1	2	3	4	Mean
1	5.30	3.69	2.97	4.20	4.04
2	4.41	5.29	3.82	5.16	4.67
3	5.96	5.67	3.78	5.93	5.33
4	6.94	5.78	4.78	5.94	5.86
5	7.80	6.65	3.60	6.37	6.10
SE		± 0.25			± 0.16
Mean	6.08	5.42	3.79	5.52	
SE		± 0.16			

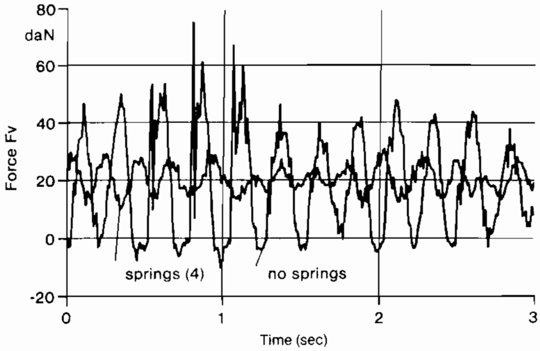

Fig. 6. Course of vertical force for suspended and unsuspended cart configuration (steel wheel, wooden bearing, laterite road, payload 360 kg).

Discussion

Results show the interaction of cart design and surface conditions for various technical parameters. The relative advantage of pneumatic tyres on rolling resistance and smoothness of the draught force is apparent. Nevertheless data also show that solid tyres can be used on laterite roads where they require draught forces that do not exceed the working capacity of a pair of oxen, for example. In this application the advantage of these wheels — prevention of punctures — may also play an important role.

The high peaks in draught force when using solid tyres can be successfully compensated for by mounting springs between axle and chassis, but this increases costs.

Conclusions

Designing animal-drawn carts is a complex process, where information about all important factors that influence the DAP transport system have to be taken into account.

With regard to the cart's technical performance, data on draught force requirements of different construction alternatives are needed for design decisions. Combining these data with information about road conditions and working capacity of locally used draught animals should result in improved cart design.

Acknowledgments

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Measurement of Draught Animal Performance

David O'Neill, Stuart Hayton and Brian Sims*

Abstract

Until recently it has been difficult to measure the physiological effects of work on draught animals in the field. Laboratory studies under artificial conditions and field studies where physiological parameters have been measured after work have given useful indications. But the new AFRC-Engineering draught animal performance data-logger modifies and records mechanical and physiological performance data during work in field conditions. Three mechanical (draught force, angle of application of draught force, speed) and four physiological (heart rate, breathing rate, body temperature, stepping rate) variables are measured. Signals from the sensors attached to the animal and the implement are conditioned electronically and then logged in a programmable recorder. This experimental tool is still being developed, for instance by including measurement of oxygen consumption, but preliminary results have shown a good correlation between power output and working heart rate. Healthy oxen can perform sustained work with heart rates twice the resting value.

Introduction

A major factor influencing the net income of farms using draught animal power (DAP) is the productivity of the animals, whether this be in terms of area tilled, litres pumped or tonnes hauled. In many developing countries financial pressures on individual farmers are such that draught animals are the only viable power source option, as tractor costs continue to rise. From a national viewpoint draught animals also provide an attractive solution to farm power needs in large sectors of the rural economy, and they are a national asset which consumes renewable resources not requiring foreign exchange.

It is, therefore, appropriate that research should be carried out to improve the understanding of the application of DAP. This view has been strongly upheld by Ramaswamy (1985), who stated that the modernisation and upgrading of DAP technology involving 400 million draught animals should be a high priority in developing countries. Efforts to make sustainable improvements in DAP technology have also been recommended by Goe (1983), Brumby (1986), Bodet (1987) and Smith (1981). An increase of only 5% in draught animal power output can be estimated from Ramaswamy (1985) to increase the power available to small farmers worldwide by more than 5 gigawatts (1 GW $= 10^9$W).

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Previous Methodology

In the need to improve our understanding of the application of DAP, one of the main priority areas is to determine how effectively, or efficiently, animals are used. To judge whether one animal/implement combination is better than another for a given set of conditions, the effects of the work on the animals and the amount of useful mechanical energy expended need to be assessed.

Traditionally, the efficiency of working animals has been assessed by either laboratory or field studies. In general, laboratory studies have focused on physiological variables of animals doing work, usually on a treadmill, whereas field studies have been oriented towards the mechanical variables. This is partly due to the difficulties of measuring physiological variables in the field.

The laboratory approach usually involves animals being subjected to controlled stresses, preferably in a controlled environment, whilst various physiological measurements are recorded. Hales and Findlay (1968), for example, examined a number of physiological variables in a regulated environment using a group of Ayrshire oxen, not performing any work. The aim of the experiment was to obtain normal and heat stress values for parameters such as respiration rate, respiratory minute volume, alveolar ventilation, dead space ventilation, CO_2 and O_2 tension and pH levels of the arterial blood for the oxen. The results of several sets of 2–3-hour duration experiments gave figures for the oxen at a 'normal' ambient temperature, at a moderate heat and also at a severe heat. In severe heat conditions a two-phase response was observed, there was an initial increase in respiration rate followed by a decrease with breathing becoming deeper and more controlled. This was interspersed with short periods of rapid shallow breathing, as animals attempted to thermoregulate whilst at the same time satisfy their need for oxygen. This experiment was time consuming and, due to invasive sensing techniques, the animals were inevitably subjected to stresses other than temperature. The applicability of the results to animals in their 'natural' environments or to working animals, in particular, may be limited.

Equipment for the measurement of physiological variables in the field has been in existence for some time, but it has generally been for equine applications only. For example Hörnicke et al. (1974) developed telemetric techniques for recording variables such as respiratory flow and oxygen partial pressure. The equipment included an airtight face-mask (with a bit), which contained several sensors. Respiratory flow was measured using a strain gauge pneumotachograph, and oxygen concentration was continuously sampled from the centre of the respiratory tube with an oxygen electrode.

This equipment allowed the monitoring of physiological variables in more realistic working conditions. However, technology which depended on somebody riding the animal was not well suited to bovine applications and, as the author acknowledged, the response time of the oxygen measuring system needed improvement.

Indian bullocks (crossbred and local animals) carrying out heavy work during summer were studied by Upadhyay and Madan (1985) in order to determine their physiological responses. A load car was used, set at 1000 kg load, and pulled for 3 hours or until the animals were judged to be fatigued. Draught force was recorded using a hydraulic dynamometer and speed was recorded so that power could be calculated. Work was continuous but physiological observations were taken only at the beginning and end of work. Rectal temperature, heart rate and respiration rate were recorded which, together with subjective observations, were used to give each animal a fatigue score. This score was based on increases above resting values. The greater the increase, the greater the score and hence the fatigue. Other observations included leg incoordination and tongue protrusion (see Table 1).

The use of the score card system seems to be of limited use as the transfer to other experiments is bound to meet with problems of inconsistency, especially with the subjectively assessed variables. If observations and recordings are made before and after work, the physiological changes taking place during work can be inferred only, thereby increasing the scope for error.

The field measurement of mechanical variables has been achieved to varying degrees of accuracy. Techniques involving measuring tapes, stopwatches and force transducers have usually been employed. A typical example is the research of Rautaray (1985), who outlined methods of recording various mechanical and physiological variables during the course of tillage operations with pairs of Indian bullocks. Three different breeds of bullock were worked in two shifts for approximately 6 hours a day in a normal work regime, carrying out tillage operations on Vertisol soils. At the end of each hour's work there was a 5-min period of observation, when the pulling force on the implement was recorded using a spring dynamometer. Physiological variables were also recorded after each hour. The animals were stopped and respiration rate and pulse rate were taken manually over 1 min. Body temperature was measured by inserting a full-length clinical thermometer into the rectum for 3 min. Mean walking speeds were measured each hour and work output in square metres/hour was calculated. Ambient air temperature and wind speed were also recorded.

The results showed that respiration rate, pulse rate and body temperature increased as a result of work, with a marked increase in respiration rate after 2–3 hours work, at high draught values. It was also observed that the animals exhibited various physical distress symptoms, such as interrupted and staggered walking, during periods of high pulse and respiration rates. This method, although providing

Table 1. Indian ox fatigue scoring system.

	Score Scale				
	1	2	3	4	5
Respiration rate per min	*Ro + 15	Ro + 30	Ro + 45	Ro + 60	Ro + 75
Heart rate per min	*Ho + 10	Ho + 20	Ho + 30	Ho + 40	Ho + 50
Rectal temperature (°C)	*To + 0.5	To + 1.0	To + 1.5	To + 2.0	To + 2.5
Frothing	First appearance	Dribbling of saliva starting	Continuous dribbling	Appearance of froth on upper lips	Full mouth frothing
Leg incoordination	Stride uneven	Occasional dragging of feet	Movement of legs uncoordinated and frequent dragging of feet	No coordination in fore and hind legs	Unable to move because of incoordination
Excitement	Composed	Disturbed	Nostrils dilated and bad temperament	Movement of eye wall prominent with excitement	Furious and trying to stop
Inhibition of progressive movement	Brisk	Free-movement	Slow walking	Very slow	Stop walking
Tongue protrusion	Mouth closed	Occasional opening of mouth	Frequent appearance of tongue	Continuous protrusion of tongue	Tongue fully out

* Ro, Ho, To represent initial respiration rate, heart rate and rectal temperature respectively.

a rough overview of the work done by the animals during the course of a day, does not provide a comprehensive picture. Data collection was such that the physiological values were not measured during work, but during a recovery period. Furthermore, the 5-min period each hour for force measurement may not have been fully representative of the previous 55 min work.

Most of the investigations concerned with the power produced by draught animals have relied on similar systems, which have allowed readings to be taken only at relatively infrequent intervals. Examples of the use of such systems are provided by Lal (1987) and Maurya and Devadattam (1985).

An increase in the accuracy of measuring draught force came with equipment capable of making continuous recordings of force, rather than taking spot readings. Developments in electronics in recent years have stimulated rapid progress both in the area of data acquisition and the design of force transducers.

Singh et al. (1988) used an electronic recording system to investigate the performance of working bullocks under varying load and climatic conditions. A wheeled tool-carrier (WTC), with trailed sledge was used to vary the load. A strain gauge load cell of 5 kN rating measured the force. An instrument box housing a signal amplifier and a chart recorder was mounted on the WTC, giving a printed copy of the force readings during work. Their experiment was carried out along a level road and time was recorded manually at set distances. At the end of each hour's work the bullocks were rested for a 5-min interval, which allowed the measurement of respiration rate and pulse rate, both of which were measured manually. This instrumentation equipment, despite its improved accuracy from a continuous record of force, had relatively crude methods of timing and measuring the physiological effects of work on the animals. Again, physiological values were not taken during work.

Further advances came with the development by the Centre for Tropical Veterinary Medicine (CTVM) in Edinburgh of a system (Lawrence and Pearson 1985) giving a more complete account of the work being done by draught animals pulling implements in realistic situations.

The equipment used on the CTVM ergometer consisted essentially of a 2.5 kN electronic load cell, a timer, an odometer and two associated electronic circuits. A trailed wheel was attached to the implements, and for each revolution the odometer produced 360 'square wave' pulses. This was equivalent to one pulse for every 5.8 mm of forward movement, allowing large distances to be measured quite accurately. The load cell was mounted so that the total force developed by the animals passed through it. Measurements of draught force taken each time an odometer pulse was produced (i.e. every 5.8 mm) enabled the instantaneous and cumulative work done to be recorded.

The CTVM system represented an important step forward in that it provided a complete record of the work done in terms of force exerted, whilst the animals were in a relatively 'normal' working environment, with readings being taken several times a second. At that time the system was not equipped to measure physiological variables.

Using the CTVM instrumentation system in Nepal (Pearson 1989), a study was carried out with the aim of providing local farmers with information on which they could base decisions concerning which animals were best suited to their particular needs. The ergometer (Lawrence and Pearson 1985) measured several mechanical variables, but did not include the effects of work on the animals. It was therefore decided to upgrade the system to measure stepping rate, respiration rate, body temperature and ambient temperature as being relevant to the assessment of an animal's physiological state. It was also decided that these variables should be logged whilst the animal was doing work, and not, as previously, by stopping work to take measurements.

Results from this work published recently provide information on the mechanical outputs, illustrating the differences in trained and untrained oxen, and highlighting the advantages and disadvantages of using different breeds. Physiological results reported are concerned mainly with the body temperature, but stepping rate and respiration rate have also been measured successfully.

This brief review has considered the various methods that have been employed to quantify the work done by draught animals. Clearly the methods vary greatly in both accuracy and achievement. The mechanical parameters measured generally have given a far from complete picture. Except for the CTVM equipment, the timing systems and frequency of measurement have been questionable. Recording of physiological parameters has also been less than satisfactory. Reliable instrumentation designed to measure physiological responses to work in field conditions did not exist.

To further our understanding of DAP, instrumentation which could measure simultaneously the physiological and mechanical parameters that define work was required. It needed to be able to log at high speed, with high precision in field conditions, whilst causing minimal interference to farmer and animal. Recently AFRC-Engineering have developed an instrumentation package meeting these needs.

AFRC Instrumentation Package

The complexity of the application of DAP, and in particular judging its effectiveness, demands an interdisciplinary approach which would enable the animal-implement to be considered as a coherent system. The performance variables, together with their interactions, could then be studied to obtain a clearer understanding of how the system operates.

AFRC-Engineering Overseas Division (OD) has developed a draught animal performance data logger, which monitors and records mechanical and physiological performance data in field conditions (Fig. 1). Design requirements of the logger required it to be compact, portable and capable of functioning under conditions of high temperature, humidity and dust. Its use must not interfere with work routines, nor impose stress on the animals. In selecting the method and type of sensor used for the physiological variables, great importance was attached to animal and farmer acceptance.

The three mechanical and four physiological variables selected were draught force, its angle of application, forward progression, heart rate, breathing rate, body temperature and stepping rate. Signals from the sensors attached to the animal and the implement are conditioned electronically and then logged in a programmable recorder with solid-state memory. In the prototype logger, which did not have a miniaturised electronic signal conditioner, the sensor signals were fed to a junction box, usually on the animals' yoke and from there to a person walking alongside wearing a backpack and carrying a small hand-held microcomputer.

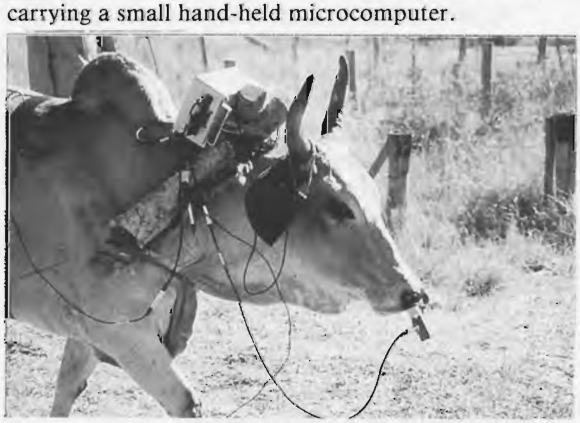

Fig. 1. Modular system in use with breathing rate and heart rate sensors attached (ILCA, Ethiopia 1988).

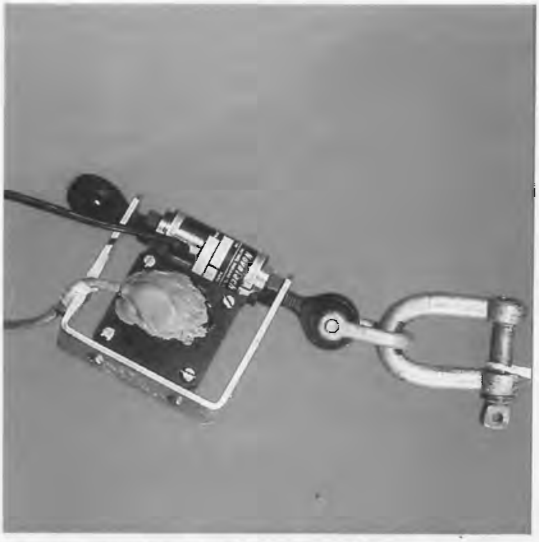

Fig. 2. Load cell with inclinometer, allowing force to be measured together with the corresponding angle of pull.

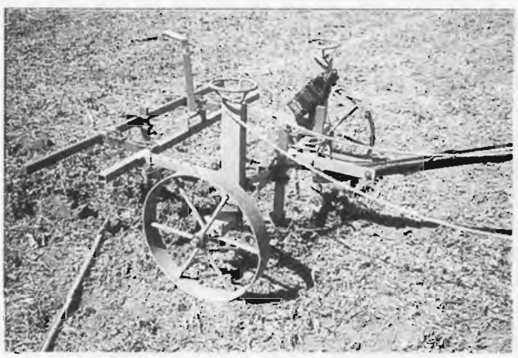

Fig. 3. Wheeled tool-carrier with mounted radar (Bhopal, India 1987).

A load cell of 2.5 or 5 kN depending on the draught potential of the animals, is used for the measurement of force. An inclinometer is attached to the load cell to measure the angle between the line of application of the force and the horizontal (Fig. 2). It is essential that the load cell is incorporated into the system so that all the force pulling the implement is transmitted through it. Care must be taken that there are no parallel linkages through which some of the draught force may be carried.

Distance travelled during work is usually measured by a microwave radar device (Fig. 3). Because of its compactness and not having to make contact with the ground, radar is preferred to the more conventional trailing wheel.

However, the radar is not accurate in tall crops, so a trailing wheel is available as an alternative sensor. With the radar system pulses are generated at fixed distances (usually about 80 mm) by the movement of the sensor relative to the ground. The generation time of each pulse is recorded allowing speed and power to be computed.

To monitor heart rate an ear clip device was designed which detects blood flow by measuring the infrared absorptivity of the ear. This clip has an array of near infrared emitters on one side of the ear and, on the other, an array of receiver diodes which are sensitive to radiation of that wavelength. As blood pulses through the ear, maximum absorptivity occurs, receiver output signal strength drops to a minimum. The signal conditioning unit identifies this and produces an electronic ('square') pulse. As with the radar output, the real time values of these pulses are recorded, and the heart rate is obtained at every beat.

The detection of breathing rate is achieved by sensing air movement through a tube adjacent to one nostril (Fig. 1). Two thermistors inside the tube, either side of a small heater, detect temperature differentials as the direction of air flow changes. It is these differentials that are used to compute breathing rate.

The stepping rates of both animals of a pair can be monitored using two separate channels within the instrumentation package. Using an accelerometer strapped to one of the animal's forelegs, the peak acceleration during the stepping cycle is recognised by the signal conditioning circuits. This peak generates a pulse signal, the exact time of which is recorded.

Body temperture was originally monitored at the animal's ear with a thermistor on the ear clip which carries the heart rate sensor. However this method was rejected because the superficial body temperature being measured was too heavily influenced by environmental changes. This led to the use of a rectal probe, which although being invasive to a certain extent, can be left in place whilst the animal is working thus causing little disturbance.

Discussion

At present, the AFRC instrumentation package is the only fully portable system available for field use that can provide a continuous record of both mechanical and physiological work performance variables. In addition to logging working heart rate it can also be adapted to monitor oxygen uptake and ventilation rate.

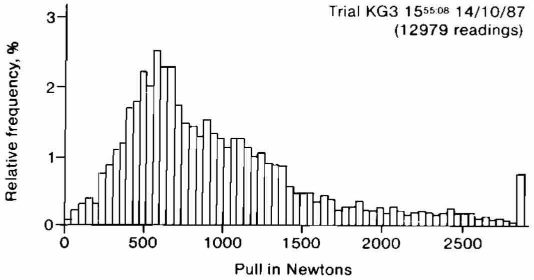

Fig. 4. Histogram of forces produced during Bakhar operations. A mean power level of 605 W, mean heart rate of 117 beats/min and a force CV of 51.9% were developed.

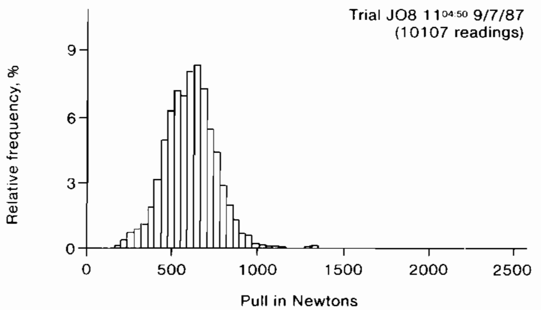

Fig. 5. Histogram of forces produced with a load car on a tarmac track. A similar mean power level of 592 W but a mean heart rate of only 109 beats/min and a force CV of 21.4% were produced.

The dominant factor in assessing draught animal work is force. If the force required to move an implement is greater than the force that the animals can produce, then the task cannot be carried out, and if the force is unacceptably high the work cannot be sustained. A variety of 'acceptable' limits has been proposed over the years. For oxen these have been in the region of 10–20% of the animal's body weight, as suggested by Devnani (1981), Maurya (1982) and Premi (1981).

Due to the nature of cultivation operations and the variability of soil conditions, a completely steady draught force requirement is impossible. Furthermore, the nature of animal movement introduces unavoidable variations in the draught force. Excessive draught force variability has generally been regarded as undesirable for the animals (FAO 1972), but the ability to quantify the effect has been possible only recently (O'Neill and Kemp 1988), through use of the AFRC package. By logging force readings several times each second a true measure of force variability can be derived and its physiological effects can be studied.

In a long series of field trials carried out in India, heart rate and power were found to be reasonably well correlated for trials in which steady-state conditions (i.e. force, speed) had developed. In some trials, however, similar mean power levels elicited slightly different heart rates. By deriving the coefficient of variation (CV = standard deviation/mean) for draught force during a test run (i.e. approximately 2 min during which more than 2000 force readings would be logged), the variability could be quantified (Fig. 4 and 5).

When the coefficients of variation were compared for these apparently anomalous results it was found that the trials with the higher heart rate rises also had the higher CVs.

This result indicates that the criterion for loading animals should not be expressed purely in terms of body weight, but that a factor should be included to take account of the variability in draught force. Further investigation should be carried out into the area of force variability, as undoubtedly a highly variable load causes increased stress to the animals, with the consequence of reducing their work output.

O'Neill and Kemp (1988) identified two serious implications for the loading of draught animals. Firstly, if highly variable or erratic loads could be made smoother, the benefits of stress relief to the animals may well be passed on to the farmer in terms of a higher work output. In practical terms this could be achieved by modifications to the design of harnesses or soil-engaging components, or, when applicable, by removing stumps and rocks from fields before primary cultivation. Secondly, laboratory-based research, in the past, may have underestimated the stresses placed on animals during work.

Another unexpected result was found when comparing the CVs of force and power. As power is the product of force and speed it was expected that the CVs would be more variable than that of force alone. In fact the opposite was discovered. Animals appear to regulate their effort compensating for variations in force by varying speed and thereby produce a relatively smooth power output. This compensatory action, however, seems to cause a heart rate rise, which indicates more strenuous work.

The vertical component of the pulling force acting on the animals can be important as recognised by Lawrence (1986), but often has been dismissed as inconsequential. This may well be the case in level ground operations but when working on slopes this force may become important. In the series of Indian field-trials vertical forces were found to vary up to almost 1000 N. As a general rule for minimum animal stress the angle of pull between the animal and the implement should be as close to the horizontal, or direction of motion if on a slope, as possible. This is because, as the draught angle increases, increases in the vertical force component are proportionately greater than the decreases in the horizontal component (according to the functions of sine and cosine, respectively). However, if a vertical component is needed for correct operation or stability of a cultivating implement, this must be provided by selection of the appropriate draught angle.

If it is found from investigation that animals are being worked at a power output well below their optimum, the farmer has, in effect, two choices. He could increase the speed at which the animals are working, or he could increase their draught load. The first option may superficially seem the simplest but is unlikely to be practical. Animals tend to walk at their own natural speed and if they are forced to increase their pace they will become unnecessarily or prematurely fatigued. The option to increase the draught load is more viable but depends on suitable implements being available. For example, draught load could be increased by using more soil-cultivation components in parallel if only shallow cultivation is demanded. By increasing the width of cultivation, the work output measured as area/time is increased but without the additional stress incurred by the animal walking at an unnatural rate.

Concluding Remarks

The experience gained by AFRC Engineering from their DAP investigations prompts the following general remarks:

(i) The main determinant of the ability of animals to perform draught cultivation operations is the draught force. The level of draught force that can be sustained depends on body weight, duration of work and the variability of the force.

(ii) The power output of draught animals is reasonably well correlated with working heart rate. This is based on the assumption that a healthy ox can perform sustained work with heart rates twice that of resting. For basic evaluations of animal-implement performance, therefore, it is necessary to measure only three parameters — force, speed and heart rate. The force should be measured at frequencies around 20 times/sec to assess its variability and potential reduction in work output.

(iii) Oxen adopt a comfortable stepping rate in the range 30–40 steps/min, at a fairly constant step length. Step length depends largely on the shoulder height of the ox and so walking speed is constrained within a fairly narrow range.

(iv) For oxen in the weight range 400–600 kg studied in India the optimum power (P_0) output can be predicted from the simple relationship:

$$P_0 = W.H_W/2 \quad \text{Watts}$$

Where W is weight in kg and H_W is height at the withers in m.

(v) Animals are used most effectively when the work demands match their work capacity. The simplest way to obtain an approximate indication of work capacity is through measuring heart rate, as this takes into account other stresses such as heat, humidity or erratic loading patterns, which can influence work capacity or work output. The power demand can be compared to the optimum (see (iv)) or assessed in terms of heart rate (see (ii)). The ability of the animal to cope with the total workload can be assessed from heart rate measurements taken after the end of work during recovery and compared to the heart rate of the animal at rest. This latter technique is particularly attractive as the only equipment required is a wrist-watch or stop-watch.

(vi) Changes in the animals' rate of energy expenditure in order to make it match their optimum power output more closely should be effected through alterations to draught load rather than alterations to speed.

Acknowledgments

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Optimising Tillage for Wetland Rice

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Abstract

Tillage is often described as the manipulation of the soil so that agriculture may be practiced. In dryland farming it is used to control weeds, conserve water and make a seedbed consistent with the crop being grown. Wetland rice has a particular set of requirements for seedbed conditions and later growth. In order to determine the tillage required for wetland rice it is best to find out what soil conditions will give good growth. However, for soils for wetland rice which are flooded and/or puddled, the specification of a soil mechanical or physical property has not been easy. Unless suitable parameters are identified then any attempt to optimise the system is limited. The object of this paper is to present information on suitable soil physical parameters to classify a paddy soil, to show how yield of rice can vary with measured parameters, to describe a rating system for tillage in rice soils, to present data which will support the system proposed and to suggest research which might be done in the future.

Introduction

TILLAGE means different things to different people but it is essentially the manipulation of the soil so that agriculture can be practiced. Manipulation of the soil in this way is as old as the agricultural history of mankind, when people stopped being hunter-gatherers and became agriculturalists. The development of tillage has in some situations gone almost full circle in that minimum tillage techniques (Lal 1985a), the use of planting holes for individual seeds (Brontonegoro et al. 1986) and broadcasting of seed (Ball and O'Sullivan 1987) are all techniques which are being considered in modern agriculture.

Tillage in dryland farming is used to control weeds, conserve water and make the seedbed consistent with the crop being grown. This statement does not imply any particular form of tillage or whether the implements are used with tractor or animal power.

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However, if it is known what type of seedbed or conditions are needed for growing a particular crop, these specifications can be obtained by the use of a known tillage system. The use of the expression soil dynamics to describe soil manipulated by tillage implement covers the specification (of crop requirements), the prescription (of soil properties) and the action needed to bring about a response. The response can be measured in terms of productivity, conservation and efficiency (Schafer and Johnson 1982).

In this paper the topic optimising tillage for wetland rice is given with the obvious thought of using draught animal power, and it is therefore appropriate to state the tillage requirements for wetland rice. Much wetland rice land is puddled, and Greenland (1985) indicates that puddling is to allow easier transplanting of the rice plants, as a means of controlling weeds (particularly because of the continuously flooded soil) and finally to reduce infiltration. Some infiltration is necessary, however, because it is the interchange with fresh water which is responsible for the supply of some oxygen in the flooded soil situation although too high an infiltration leads to a waste of water. To establish this condition for rice needs a special set of conditions which have been difficult to quantify because of the inability to take physical measurements in puddled soils. Recent attempts have shown, however, that physical measurements can be made and differences do occur in soils puddled in different ways (Guidi et al. 1988; Tranggono 1988; Tranggono and Willatt 1988; Sharma and De Datta 1985; Keersebilck and Soeprapto 1985).

If these differences can be quantified and the tillage input specified then a means of optimising the tillage system used for wetland rice is possible. It is also possible, knowing these conditions, to take the specification one step further to include in the rice-based cropping system upland crops as well. One of the most important factors to be considered in specifying a system which may optimise tillage in wetlands is the soil. Soils of different types react in different ways (Willatt and Tranggono 1987), and it is this difference which must be first addressed when considering such a system. Soil is often the determining factor in tillage experiments, and many years ago Russell (1956) noted that the results of experiments, when looking at deep tillage, showed only 50% gave improvement with deep tillage, and that most of the differences in the results were soil-related.

In more recent times work on minimum tillage has shown that minimum tillage benefits are soil-related, and in cool, wet climates light soils can be minimum-tilled but in warmer, drier climates heavier soils should be used.

Soil Parameters

Suitable soil physical or mechanical parameters in wetland situations are not always easy to measure; however, recently successful attempts to measure bulk density (Sharma and De Datta 1985), porosity (Guidi et al. 1988) and soil mechanical properties (penetration resistance — Tranggono 1988) have given some useful information in relation to the effect of puddling, amount of puddling or the method of puddling. For example the information of Guidi et al. (1988) presented in Table 1 shows that a water buffalo-drawn plough gave very similar results to the conventional rototiller on skids, whereas a floating rototiller is different. The floating rototiller gave the larger total porosity when compared to the other two treatments in December. However, 3 months later at harvest time the conventional rototilled and the water buffalo-drawn ploughed soil had increased in total pore space at 50 and 100 mm, while the floating rototiller soil had decreased in total pore space at these depths. This shows that puddling the soil in different ways can cause different reactions.

Using a sampler designed for taking bulk density samples in puddled soil, Sharma et al. (1988) showed that puddling changed bulk density in a clay soil; however in a clay loam soil puddling and minimum tillage gave the same result while zero tillage is different (see Table 2). The greatest change in bulk density is in the clay soil with a much lower bulk density than the loam in the puddled conditions. Penetration resistance was also different for tillage treatment with puddling giving the lowest resistance in the clay and the difference occurring only at 20, 70 and 120 mm. In the clay loam, consistent with bulk density, zero tillage has the greatest resistance at the surface (20 and 70 mm). The presence of a hard pan was clear in the clay loam at about 120 mm. Values ranged from 0 to 0.6 MPa in the clay and 0–1.2 MPa in the clay loam.

In specifying mechanical properties of a puddled soil, Tranggono (1988) measured bearing capacity with flat discs of varying diameter during the rice-growing season for a clay and a loam soil. He also measured depth to hard pan and the penetration resistance of the hard pan at 5 cm depth. Bearing capacity measurements indicated that significant differences occur due to puddling at both sites (Table 3). These techniques are sufficiently sensitive to detect differences between rates of puddling (i.e.

Table 1. Total porosity (cm^3/g) measured by mercury-intrusion porosimetry after various ploughing treatments (Guidi et al. 1988).

	December 1985 Depth (mm)			March 1986 Depth (mm)		
Treatment	50	100	150	50	100	150
Rototiller standard	0.174	0.184	0.184	0.215	0.203	0.174
Water buffalo-drawn plough	0.170	0.184	0.190	0.207	0.206	0.182
Floating rototiller	0.192	0.203	0.205	0.188	0.186	0.180

Table 2. Bulk density values as a result of tillage treatment at 10 cm depth (Sharma et al. 1988).

Treatment	Bulk density (mg/m^3)	
	Clay	Clay loam
Puddled soil	0.66	0.98
Minimum tillage	0.97	0.99
Zero tillage	0.99	1.17

Table 3. Effect of tillage methods and degree of puddling on bearing capacity of puddled soil.

Treatment	Bearing capacity (kPa)				LSD 5%
	P0[a]	P1	P2	P3	
	Regosol (Loam) — Mojosari				
Animal	23.4	14.8	12.0	9.5	
Tractor	22.3	11.2	9.2	8.2	0.17
	Vertisol (Clay) — Ngale				
Animal	30.1	18.6	12.6	9.7	
Tractor	31.6	18.0	12.0	9.1	0.18

[a] P0 Soil flooded no working;
P1 Soil flooded ploughed and harrowed once;
P2 Soil flooded ploughed and harrowed twice;
P3 Soil flooded ploughed and harrowed three times.

Table 4. Depth to hard-pan (cm) for two soils at different locations using animal traction and two-wheeled tractor.

	P0*	P1	P2	P3
	Regosol (Mojosari)			
Animal	10	13	16	19
Tractor	10	18	22	27
	Vertisol (Ngale)			
Animal	13	16	21	25
Tractor	12	23	28	34

* See Table 3 for legend of descriptions.

the number of times the soil is worked under water), even though values of bearing capacity are relatively small. Another important factor found was that the depth to the hard pan varied with preparation treatment (Table 4), and was strongly correlated with soil resistance at 5 cm depth in this hard pan. Also noted from Table 4 is the fact that even though puddling gave the major differences, tractor-powered tillers and animal-drawn ploughs have different values of depth to hard pan. Bearing capacity of the puddled soil is surprisingly similar for the two different tractive systems, more so in the clay than in the loam. Soil differences are also apparent.

Rice Yield

Having established that there are measurable differences in soil physical properties in 'wet' puddled soils, it is now possible to see if this information can be related to variability in yield. Relationships do occur for yield variability of dryland crops with physical properties (e.g. Tranggono and Willatt 1988), where yield of maize was linearly correlated with penetration resistance. To determine if a relationship can be found between soil mechanical properties and yield of rice, paddies in the two soils referred to earlier (Regosol-loam and Vertisol-clay) at different sites were sampled and used to correlate yield and bearing capacity and depth to hard pan (Tranggono 1988). To do this the paddy was divided into 1 m square plots, harvesting each of these subplots individually and taking the appropriate physical measurements in each subplot, the major blocks having 625 units (i.e. 25 × 25 m). The results were plotted graphically and an example for the loam soil (Regosol) is given in Fig. 1a (yield variation) and Fig. 1b (bearing capacity). The areas of high yield correspond to greater depths to the hard pan. In fact in this conventionally prepared paddy the edges of the paddy field had deeper puddled soil than the centre and confirmed earlier unpublished data (Tranggono and Willatt) where this was also observed.

The correlations between yield and depth to hard pan and bearing capacity are given in Table 5, for the two soils as well as a combined equation relating yield to both parameters, R^2 values being between 0.77 and 0.88. When plotting the data there was a suggestion of curvilinearity, but taking logarithms of the data did not improve R^2 at all. Increasing depth had a positive effect on yield but increasing

Table 5. Correlation between rice yield (t/ha) and depth to hard-pan (cm) and bearing capacity (kPa) of puddled soil.

Ngale (Vertisol)	
y = 1.9 + 0.27 (depth)	r^2 = 0.88
y = 8.4 - 0.13 (bearing capacity)	r^2 = 0.77
y = 2.7 - 0.24 depth - 0.02 (bearing capacity)	r^2 = 0.88
Mojosari (Regosol)	
y = 3.5 + 0.33 (depth)	r^2 = 0.83
y = 10.8 - 0.13 (bearing capacity)	r^2 = 0.85
y = 7.8 - 0.15 depth - 0.08 (bearing capacity)	r^2 = 0.88

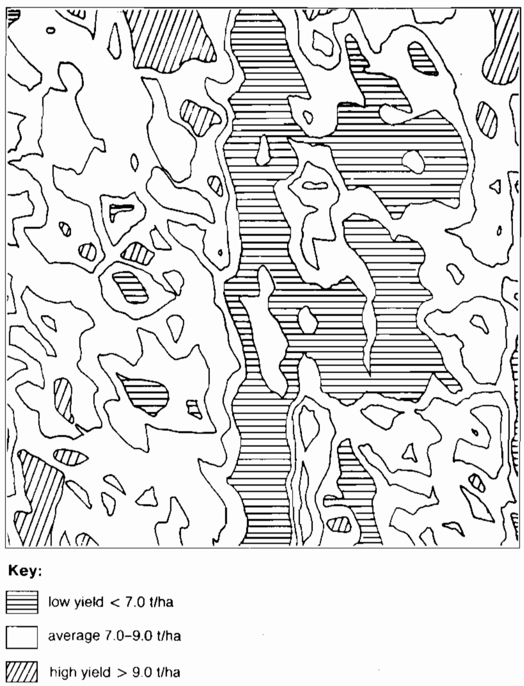

Fig. 1a. Variability of rice yield in a Regosol (Mojosari).

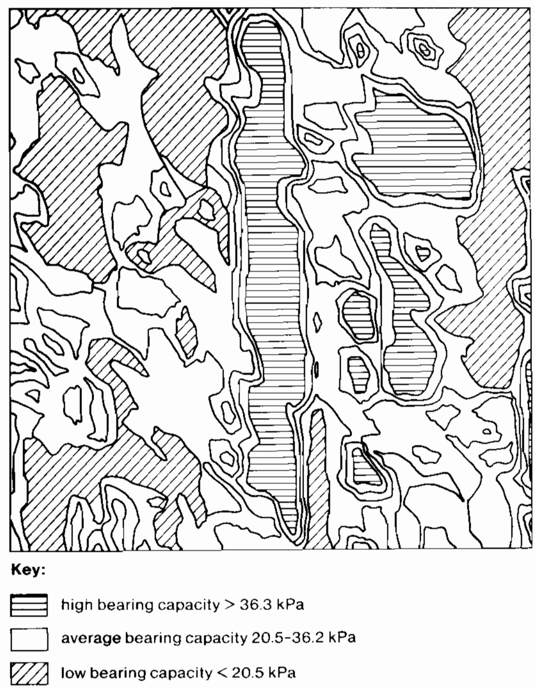

Fig. 1b. Variability of bearing capacity in a Regosol (Mojosari).

bearing capacity, even though it is very low, had a negative effect on yield.

In the work reported by Sharma et al. (1988), yield also decreased with increase in soil penetration resistance at transplanting, and this effect varied with soil type. The Sharma et al. (1988) experiment related puddling (two × 0.15 m ploughings and three harrowings), minimum tillage (rototilled) and zero-tillage treatments, thus a variety of land preparation techniques were used. Some differential puddling was done and the puddled treatment was as good as or better than the other treatment. In a review in 1985, Lal (1985b) came to the conclusion that the beneficial effect of tillage in wetlands was dependent very much on soil type, citing examples in which puddling had no significant effect on yields.

Following his earlier findings, Tranggono (1988) set up an experiment with controlled amounts of puddling in order to produce different mechanical/physical properties. It was from this experiment that results presented earlier were obtained (Tables 3 and 4), which showed the objective was successful in reproducing the physical conditions found in the conventionally produced rice paddy (i.e. varying depths to hard pans and different bearing capacities). The use of animal power with the traditional plough body, which varies in shape from place to place in Indonesia (Turner et al. 1984), was the basis of one set of treatments, and the two-wheeled tractor with a mouldboard-type plough was the basis for the other set of treatments. Thus the basic implement was the same; the harrowing treatment was, however, different. The animal-drawn treatment was the standard wooden harrow, whereas the tractor had a rotary-type harrow.

As already indicated when discussing physical properties, the animal and tractor treatments gave differences in physical properties, particularly depth to hard pan, but the number of workings was more significant. A correlation with yield was found with physical properties, but because the depth to hard pan is much greater than in the variability experiment reported above, there was a yield maximum which corresponded to a particular depth to the hard pan. The maximum yields and depths to hard pan are given in Table 6 with number of workings. Thus maximum yield can be related to the amount of tillage. Because strength of soils is usually implicated with root growth, and therefore yield, the data for yield were plotted against soil resistance at 5 cm in this hard pan (Fig. 2). Maximum yield occurs in three cases where soil resistance is about 2 MPa, the resistance usually associated with the potential impedance of root growth.

The implication of this work is that there is a maximum yield which is related to measurable physical properties and therefore controllable by tillage. Thus tillage systems can be devised which may make it possible to improve growth and also to predict yield. It will be noted in Table 6 and Fig. 2 that although the amount of tillage is obviously important, soil type has a major effect on yield determination.

Table 6. Yield maximum and corresponding depth to hard-pan and number of workings.

		Yield (t/ha)	Depth (cm)	No. of workings
Regosol (Loam)	Tractor	5.1	23	1
	Animal	4.5	21	2
Vertisol (Clay)	Tractor	6.4	28	2
	Animal*	6.2	25	3

* Yield still increasing in this treatment.

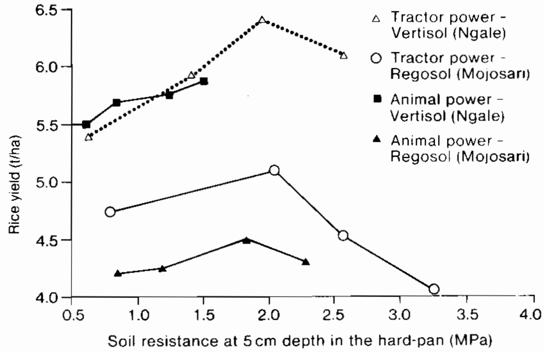

Fig. 2. Relation between rice yield and soil resistance at 5 cm depth in the hard pan.

A Tillage Rating System

Rating systems for tillage have been discussed in recent times, and Lal (1985a) gave a suitability guide for tillage in tropical soils including a system for wetland culture to decide whether minimum tillage could be used to prepare land for paddies. He chose five parameters which he saw as important, including clay content, cation exchange capacity, soil permeability, endurance to traffic and days available for seedbed preparation. In Table 7 the rating values of these soil parameters are listed with the criteria for minimum tillage being the lowest rating, thus for low clay content minimum tillage was best. Four of these parameters can be measured easily and three modified by ploughing or working: smearing the hard pan which can change permeability; endurance to traffic can be changed by working and quantified by measuring bearing capacity in the wet phase or penetration resistance in the dry phase; days available for seedbed preparation depends on many factors, perhaps the most important being how long the soil takes to dry to a water content which will give satisfactorily tilled soil in the dry phase in a rice-based farming system. The best water content for this is considered to be

Table 7. Tillage rating system relating soil factors needed for the production of wetland rice (Lal 1985a).

Clay content (%)	C.E.C. (mol/kg)	Soil permeability (mm/day)	Endurance to traffic	Days available for seedbed preparation	Rating[a]
<10	<50	<4.5	very good	<15	1
10–25	50–100	3.0–4.5	good	15–25	2
25–40	100–150	1.5–3.0	fair	25–35	3
40–55	150–200	0.09–1.5	poor	35–45	4
>55	>200	<0.09	very poor	>45	5

[a] The lowest number favours no-tillage.

Table 8. Rice-growing soils and classification for tillage suitability (Lal 1985a).

	Site			
	Regosol - Loam		Vertisol - Clay	
Parameter	Value	Rating	Value	Rating
Clay content	22%	2	75%	5
CEC	n.m.[a]	3	n.m.	4
Permeability mm/day	50	4	0.1	5
Endurance to traffic (bearing capacity)	10 kPa	4	15 kPa	3
Days available for seedbed preparation	[b]	2	[b]	3

[a] Estimated, not measured
[b] Based on length of time between harvest and when soil reached lower plastic limit water content.

the 'lower plastic limit' water content. At this level the energy required to pulverise the soil is low and the friability high (Utomo and Dexter 1982).

The results from the two sites discussed earlier using the proposed ranking system data are presented in Table 8.

The following modifications and assumptions were made: the CEC was not measured but the value in the clay was assumed to be greater than in the loam; endurance to traffic was measured as bearing capacity of the puddled soil; and the days the soil took to dry to the lower plastic limit water content were used instead of days available for seedbed preparation as already mentioned. Using these criteria it is suggested that minimum tillage is more appropriate in the Regosol than in the Vertisol. The data presented in Table 6 can be used to check this proposal, i.e. in the Regosol less tillage is better for rice yield, maximum yield being obtained for one tractor working and two animal workings, whereas in the Vertisol these maximum yields are obtained with two and three workings, respectively.

Thus an appropriate set of soil parameters can be used to predict tillage requirements to give maximum yields, and the results of experiments carried out independently (indeed started before the rating system was published) support the system proposed.

It is appropriate to see if any modification to the Lal system can further assist in the specification of tillage requirements for wetland rice. The quantification of the endurance to traffic with a bearing capacity measurement of the soil in the wet unworked flooded phase could be a more appropriate measurement than the descriptive one specified. In fact the ranking offered by Lal seems inappropriate in relation to puddling. If the soil is very poor and collapses it would be better not to work it as often as one which can support traffic. Replacing this with the bearing capacity a rating of 1 for a bearing capacity less than 20 kPa with 15–20 kPa increments would seem logical. Replacing days available for seedbed preparation at this stage is a suggestion which cannot be made with any certainty.

Tillage systems can be devised for both dryland and wetland soils and where it is possible a specification of the best way to till and the number of workings needed is given. In wetland the puddling process is dominant and as well as the action of the plough, the treading (and pugging) of the animals and the farmer must be considered. The experimental evidence is that the number of workings is more important than the type of working, a factor which has been shown in laboratory experiments where Tranggono (1988) found that stirring soils in a beaker will give similar values for bearing capacity as in the field experiment.

One aspect in wetland soils which has not been discussed, but on which some work has been done, is whether it is better to produce a hard pan in the soil at plough depth and not to puddle at all. Much of this work has been done in light soils (Lal 1985b) and if the criteria suggested by Lal (1985a) are used; low clay content rating 1; low CEC rating 1; high permeability rating 1, in a dry condition probably the soil has a high bearing capacity (i.e. good for traffic passage-rating 1 or 2), and finally days available for seedbed preparation in the unmodified system is unpredictable. Therefore, for light soils minimum tillage is appropriate but leaching losses must be reduced, hence the need to compact the subsoils.

Summary

To sum up the work done so far, it is appropriate to quote the work of a number of authors:

Lal (1986) said rice yields for no-till and puddled soil with high fertiliser application were similar but with low fertiliser application puddled soil was better. This could have been the experience in traditional areas before fertilisers were used extensively, so that puddling is a technique worked out and handed down over years. In many traditional rice-growing areas where the same land has been used for hundreds of years (Setten van der Meer 1979) this is possible.

Ogunremi et al. (1986) came to the conclusion that the tillage requirements for lowland rice should be determined in terms of the water management practices and soil texture. Working with clay soils they found yield was improved by compaction of the subsoil.

Tranggono (1988) concludes the physical/mechanical properties of a puddled soil are determined by the amount of tillage which in turn affects yield and the state of the soil after harvest. Yield of upland crops in a rice-based cropping system is also influenced by the puddling process. However, the major differences were caused by soil type.

Research Needs

Tillage research can take one of two major forms. The first relates to how often the soil should be worked and whether minimum tillage or deep working are appropriate strategies. The second relates to the type of implement and designing new shapes, and testing these against the standard (a 'conventional' implement) or simply introducing a different already existing plough into an existing system.

In both cases the need to specify and measure soil properties cannot be overemphasised, and indeed much has already been said on this topic here and elsewhere. To undertake tillage research and to describe the appropriate tillage system, one should consider for wetland rice that traditional systems have been in existence for hundreds of years. These have already been mentioned and the history of puddling and growing wetland rice has been discussed in relation to Indonesia by Setten van der Meer (1979).

To do research in this area and to unravel why many of the existing systems work, and then transfer this knowledge to areas to where there are problems, is appropriate. When this is done the objectives should be to produce the highest yields for minimum energy and time input (cost).

A standard experiment similar to that done by Tranggono (1988) would be an appropriate place to start. The parameters to be measured in puddled soil include: depth to hard pan, bearing capacity of puddled soil or strength of hard pan. Time for preparation, energy inputs, yield of rice and the ease of ploughing after rice (draught animal power) are all appropriate study areas.

Using such information will allow simulation modelling of an appropriate system (McMahon et al. 1985) to occur, or suggest the use of a tillage rating system (Lal 1985a). For wetland rice soil this approach is as satisfactory as for dryland systems. In both cases it is ultimately the crop requirements in the soil that are the determining factors.

A theme which is found in a number of papers is the need to compare puddling with minimum tillage and how these treatments compare for yield production (Sharma et al. 1988; Sharma and de Datta 1985). This is consistent with the theme of this paper.

Acknowledgments

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Harnessing for Cattle and Buffaloes: Options and Research

Paul Starkey*

Abstract

Yokes, breastbands and collars link animals to implements. Existing yokes are widely considered inefficient but no consensus exists on how harnessing can be improved. Traditional yoking systems have sometimes outperformed 'improved' harnesses. Farmers seldom regard harnessing as limiting and few recent designs have been adopted. The widespread use of horn/head and withers/shoulder yokes will continue. The term 'neck yoke' should be avoided. Little objective evidence exists to distinguish the efficiency or comfort of yokes. Improvements may come from correct attachment of existing designs and small changes in contouring and padding.

Collars and three-pad harnesses are rare. With large contact surface and low pulling angle they are considered efficient and comfortable, but objective, replicated research has not substantiated claims for high percentage improvements over yokes. Some workers have confounded harness type with animal number. At low draught, single animals match the power of pairs, but have lower endurance. Worldwide, single oxen are rarely used for heavy operations. Large teams provide sustained high power but few studies have quantified team efficiency. Scope exists for thorough research on mechanical and physiological attributes of harnesses. It is questioned whether physiological stress indicates harness inefficiency or harness comfort.

Introduction

HARNESSING is a fascinating subject since it appears that most scientists and development workers feel that *something* should be done to improve harnessing, but there is no clear consensus on *what* that something should be. At the last ACIAR conference on animal power in 1985, a general recommendation was made for further research on harnessing, but there were no suggestions as to what exactly should be studied (Copland 1985). Comparable recommendations have been made at international workshops held in Southern Africa (SACCAR 1987) and West Africa (Starkey and Faye 1988), and several researchers have made similar calls in publications (Smith 1981; Goe 1983; Matthews 1986; Bordet et al. 1988). Quite passionate debates have been held at workshops on the relative advantages and disadvantages of different harnessing systems. However, there appears to be little recent evidence that farmers themselves have been sufficiently convinced by the various 'improved' harnessing systems on offer to actually adopt them.

The subject of harnessing appears to have been well documented, and analytical reviews have been produced by Hopfen (1969), CEEMAT (1971), FAO/CEEMAT (1972), Devnani (1981), Viebig (1982), Barwell and Ayre (1982), Duchenne (1984), Matthews (1986), Starkey (1989) and Poitrineau (1989). This paper draws on research for the book 'Harnessing and Implements for Animal Traction' due to be published by GTZ (Starkey 1989). It will aim to review recent research and development initiatives relating to harnessing, and where possible to clarify some of the apparent areas of controversy. Emphasis will be on bovine harnessing systems, since these are most widely used in tropical regions.

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Clarification of Definitions

In this paper the word harness will be used to cover all the elements involved in the 'transmission' system linking the animals to their working implements (ploughs, carts etc.). This follows precedents set by many review works on this subject including Hopfen and Bielsalski (1953), Hopfen (1969), FAO/CEEMAT (1972), Barwell and Ayre (1982) and Viebig (1982). Thus the topic of 'harnessing' includes yoking systems, as well as the collars, straps and fittings used for hitching and controlling horses (and other animals) which are commonly thought of as 'harnesses.'

The wide range of yoking types falls into two main categories, those tied to the horns of the animal and those taking power mainly from the 'withers.' The 'withers' of an animal refers to the part of the back that is over the shoulders, directly above the first thoracic vertebra (in Zebu cattle the withers are immediately in front of the hump) (Fig. 1). In historical studies on yoking types the terms 'horn yoke' and 'head yoke' have been used synonymously for yokes tied to the horns (Fenton 1973). The terms withers and shoulder yokes have also been interchanged (Fenton 1973). Technically the shoulders are below the withers, and there are good arguments for dropping the term shoulder yoke, as it misleadingly implies that the power is applied from the shoulders. However, since the actual meaning of *withers* is not widely understood, the term shoulder yoke can be quite useful in distinguishing between different yoke types. Horn/head yokes are occasionally used in front of the horns, where they are described as forehead yokes. More commonly they are fitted behind the horns, and in this position they have sometimes been called 'neck yokes.' However, the use of the word 'neck' has been the source of considerable confusion in the international literature. Hopfen (1969) classified yokes tied to the horns as head yokes and described yokes taking power from the withers as 'neck yokes.' Ramaswamy (1981) and Pathak (1985) followed a similar convention. In contrast FAO/CEEMAT (1972) classified the yokes tied to the horns as 'neck yokes,' and those resting on the withers as shoulder yokes (Fig. 1). Viebig (1982) used a similar classification, although he preferred the term withers yoke to shoulder yoke. Two recent specialist texts on yoking systems have followed the Hopfen definitions and used the term neck yoke to describe the withers/shoulder yoke (Devnani 1981; Barwell and Ayre 1982).

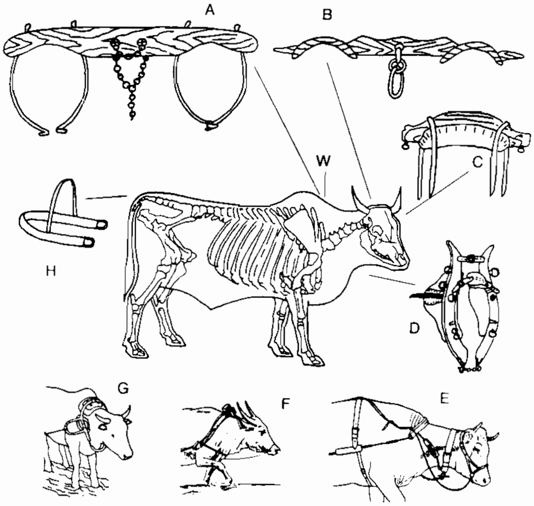

Fig. 1. Some harnessing options for cattle and buffaloes. A — Withers/shoulder yoke. B — Horn/head yoke. C — Single forehead yoke. D — 3-pad collar. E — Single 'flexible' withers harness. F — Single withers yoke. G — Single 'Allahabad' collar yoke. H — Breeching strap. W — Position of the 'withers.' (After: Starkey 1989; Hopfen 1969; FAO/CEEMAT 1972; FSERT undated; Ayre 1981.)

Thus although all texts agree that there are two very distinct categories of yoke, depending on the context and source, the words 'neck yoke' can refer to either of these different types. Since the neck is defined as the part of the body between the head and the thoracic vertebrae, both yoke types can indeed be claimed to rest at one or other extreme of the neck. To avoid further confusion it is recommended that from now on the use of the term 'neck yoke' should be avoided. Thus the major yoke types will be classified here as *horn/head* yokes for those tied to the horns, and *withers/shoulder* yokes for those taking power from the withers.

Forehead Yokes

Forehead yokes are tied in front of the horns, and although examples of these may be found in Europe, Latin America and Africa, they are quite unusual. While single forehead harnesses have been used effectively in Germany, the use of double forehead yokes is uncommon. In one controlled study in Bolivia, using a circular, experimental track, forehead yokes were found to allow greater maximal force and greater overall power over a 6-hour period than head yokes tied behind the horns, withers yokes or even three-pad collars (Céspedes 1981). However, when ths research was followed up in Mexico using much larger animals, no significant differences between the yoke types could be detected (Céspedes 1984, cited by Sims 1987). It seems agreed that forehead yokes require more careful fitting and padding than other forms of head yoke, and that there may be greater risk of injury to the head if they are not correctly fitted. Most of the other characteristics of forehead yokes are similar to the more widespread designs of horn/head yokes.

Horn/Head Yokes

Most head yokes are tied behind the horns. Such yokes are almost universally used in Latin America and they are commonly employed in parts of West Africa and Southern Europe. They are used mainly (but not exclusively) with humpless cattle. Simple uncarved wooden poles can be used as head yokes, but it is usual to carve the yokes in such a way that they both fit the heads and also have grooves and protrusions to allow easy and firm attachment of the ropes or straps. A wide variety of shapes can be used (de Oliveira et al. 1973) but there appears to be no scientific evidence that the different designs of head yoke have a significant impact on working efficiency, provided they are properly secured.

Horn/head yokes are considered most suitable on cattle with relatively short, strong necks and good horns. Once a head yoke has been firmly tied to a pair of animals, they are less free to toss their heads and horns. This provides greater safety and confidence to inexperienced users and prevents the animals damaging each other with their horns. Some people consider the loss of free head movement causes the animal significant discomfort, and it reduces the ability of animals to ward off flies.

As head yokes are firmly attached to the horns, the yoke can be used to apply forces in several directions. For example, in forestry operations animals can lift the ends of logs by raising their heads, and they can apply powerful braking forces to restrain a tree trunk moving too quickly down a hill. When implements and carts are pulled by a rigid drawbar rather than a traction chain, head yokes that are securely fastened to the animals can facilitate braking and reversing. In similar circumstances, withers yokes that are not rigidly attached to the animals may ride forward onto the heads of the animals.

There seems no objective evidence to suggest that correctly fitted head yokes differ significantly from withers yokes in overall comfort. Nevertheless discomfort may be observed when the vibrations of work appear to be transmitted directly. In addition the movement of one animal can cause the neck or head of its partner to be held in a twisted position.

Withers/Shoulder Yokes

Withers yokes are numerically the most important system of harnessing in the world. They are almost universally used in Asia and Ethiopia, and are widely used in eastern and southern Africa and parts of West Africa. Historically they were important in certain areas of Europe and North America. In their simplest form they are just wooden poles with small descending pegs (sticks) to restrict lateral movement. These pegs may be joined by a loose rope, chain or strip of hide, but this has no draught function. The wooden yokes may be shaped into double bows to more closely match the shape of the withers, thus giving a greater surface area of contact. Starkey (1989) suggested that such simple shaping may well be the simplest and most cost-effective means of increasing the comfort and therefore the effectiveness of a wooden yoke. Withers yokes may also be lightly padded, and in Ethiopia skins are used for this purpose.

Withers yokes can be very simple and easily manufactured with little carving. They allow the animals to move their heads freely, and because they do not require horns, they can be used with polled cattle or even equines. As withers yokes are not attached securely they can move relative to the skin; unpleasant abrasions or yoke galls can develop when such movement is prolonged or excessive. Withers yokes are designed to transmit forces during forward motion only and they cannot easily be used for braking carts, or for reversing, unless a back *breeching* strap is used to prevent the yoke moving forward and onto the animals' heads.

Single Yokes

Both head yokes and withers yokes can be used with single cattle, but since *cattle* are seldom used singly for field operations (as opposed to transport), single yokes are relatively uncommon. In parts of China and Southeast Asia single buffaloes are commonly worked with withers yokes in the form of an inverted V. In these same areas cattle are usually worked in pairs, although in parts of China single oxen may be worked with yokes similar to those used with buffaloes. Single yokes are generally employed with relatively large animals.

While with double yokes the implement is attached to the centre of the yoke, with single yokes one attachment point is impractical. The force of the single animal must be transmitted from the yoke to traces or shafts attached to either end of the yoke and which pass back on either side of the animal. For transport purposes the shafts can attach directly to the frame of the cart and the yoke may even be permanently fixed to the shafts. For crop cultivation the two traces are generally attached to either end of a small pole known as a *swingle tree*, and the workload is applied to the centre of this pole. One possible technical advantage of single yokes is that the attachment points of the shafts or traces are often lower than they are on double yokes. Lower attachment allows a lower angle of pull, so that less of the animal's power is used in 'lifting' forces. However, a single yoking system may be more complicated to set up and work with, as the two traces and swingle tree seem more liable to become caught up under the animal's feet during turning at the end of a row than one traction chain or beam. When using a single animal, the mutually reinforcing effect of two animals is lost.

Research Interest in Single Yokes

In many African countries research and development workers have advocated the use of single oxen, particularly for light operations, such as sowing and weeding, but this has seldom been adopted (Matthews and Pullen 1976; Starkey 1981; Viebig 1982). In the last few years research and development work on the yoking or harnessing of single oxen has increased substantially and in 1988 there were few countries in Africa without one or more programs investigating or advocating the use of single animals (Starkey 1988). Nevertheless this fashion has yet to be widely adopted by farmers.

Some of the enthusiasm for single yokes was stimulated by the International Livestock Centre for Africa (ILCA) which in 1983 reported 'ILCA has found that a farmer does not need to have two oxen for cultivation' (ILCA 1983). This statement referred to research on single withers yokes and shortened *maresha* ards as one technological option for farmers in the Ethiopian highlands who only had one ox (Gryseels et al. 1984). Although the research itself was valid, subsequent simplified reports and news items led to the misconception that ILCA was advocating a general use of single animals in Africa.

The early optimism for single yoke technology reported by ILCA staff had been based on the initial on-station studies. However, when ILCA scientists conducted large scale on-farm 'verification' studies, they identified several important disadvantages that tended to offset the well-publicised advantages. The traditional long-beamed *maresha* is normally attached directly to the double yoke, and this provides the Ethiopian farmers with good handling characteristics, and allows them to easily lift the plough when encountering a stone, or when turning. In contrast when a single yoke is used, the shortened maresha has to be attached to a trailed swingle tree and this arrangement does not provide such stabiltiy and manoeuvrability. This, together with cultural influences and the problems encountered with the skid, led the majority of farmers involved in the 'verification' trials to revert to using double yokes. Indeed almost all the 1200 farmers participating in the trials yoked their one ox together with an ox of another farmer for the primary and secondary ploughing. Fewer than 5% of the cooperating farmers used the single yokes even for subsequent lighter tillage. It was concluded that while the single-ox plough might have some applications for secondary tillage under favourable conditions, it was unlikely to replace the use of paired oxen in primary land cultivation in the Ethiopian highlands (Jutzi and Goe 1987).

Advantages and Disadvantages of Single Yokes

It is misleading to imply that simply by using a single yoke, one animal can actually replace two animals. A single animal can often achieve in a day more than half of that which would have been achieved by a pair, and for a few light operations a single animal can match the daily performance of a pair. This does not necessarily imply greater efficiency of the yoking system; if the animal achieves more it is because it is working harder; to achieve the same result a single animal may have to work twice as hard as a comparable animal in a pair. At very low implement draughts (for example single-row seeding in light soil), a single animal can work at the same rate as a team, simply by pulling the implement at normal speed; the power output of one animal can equal the power of two. However, at higher implement draught, the single animal will slow down, while a pair will be able to walk at normal speed for longer periods and so work at a faster rate. The implications of such a situation for speed, draught and power output are illustrated in a very simplified way in Fig. 2.

The extra work that a single animal has to perform, compared with one in a pair, is not 'free,' for it will require more energy from feed than when

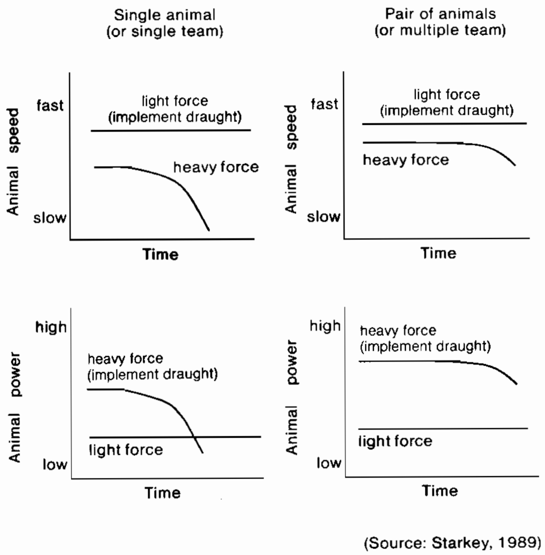

Fig. 2. Simplified graphs illustrating general relationships between animal numbers, speed, power and time for animals pulling implements of very low draught and also higher draught. (After Starkey 1989.)

it is worked as part of a pair. A working single animal will not normally by itself require as much feed as two animals, and since there is only one basic maintenance requirement, that 'marginal extra' amount of work can appear quite efficient in terms of energy. However, the limitations imposed by both grazing time and the physical bulk of poor roughage makes it difficult for a single animal to eat enough during normal grazing to make up for the extra work. For a short time this may not matter (the animal will simply lose weight), but if animals are to be regularly worked as singles, the extra feed needed for the extra work may have to be supplied in a more concentrated form as a supplementary feed. The 'marginal extra' feed can therefore be quite costly since concentrated feeds are more expensive than rough grazing. If supplements are required it may well cost more in monetary terms to feed a single animal than it does to feed a full working pair existing on grazing only. Naturally circumstances vary greatly, and there will be situations in which it is more appropriate or cost-effective to use single animals, and others when pairs will be preferable.

Multiple Hitching

Multiple hitching can be abreast or in tandem. Animals harnessed with collars or breastbands are frequently hitched abreast, with their two swingle trees joined by an *evener*. With equally matched animals the work is applied to the centre of the evener, but with animals of different strengths, the attachment point is moved away from the weaker animal to give it a longer lever on which to pull. With large teams of independently harnessed animals several eveners can be used in a hierarchical pattern, but this is uncommon in tropical countries.

The hitching of pairs of even single animals in tandem has been a common practice for both agriculture and transport in many regions. For multiple hitching of oxen, chains pass from yoke to yoke to link the animals, while with hitching of horses, donkeys or mules traces of the leading pair pass back to additional swingle trees in front of the second and subsequent pairs. In Asia the use of pairs of animals for crop cultivation is the norm but farmers in the heavy black cotton soil (Vertisol) areas of India frequently hitch two or three pairs of oxen to a single mouldboard plough to achieve penetration in hard soils. In Botswana the use of teams of at least three pairs of cattle is the normal practice, and teams can have as many as 16 animals in eight pairs. In such large teams it is usual to include all available adult animals — oxen, bulls, cows and heifers. Interestingly farmers with fewer than six available animals consider ploughing impracticable, yet there has been little acceptance of the 'lower draught' farming techniques developed by researchers between 1970 and 1986 (Gibbon et al. 1974; Eshleman 1975; EFSAIP 1977–86). Elsewhere in southern and eastern Africa, including parts of Angola, Kenya, Mozambique, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe there are certain areas where it is normal for four or six animals to be yoked for ploughing. In other localities in the same countries it is usual to work only two animals at a time. The use of multiple teams in northern and western Africa is uncommon.

It has been widely assumed that hitching animals in large teams leads to a decrease in overall efficiency, perhaps of the order of 7.5% per additional animal. The figure of 7.5% came from the report of Scherrer (1966) of trials in Africa and Madagascar for the Centre d'Etudes et d'Expérimentation du Machinisme Agricole Tropical (CEEMAT) in France. The information was extracted for the publications of CEEMAT (1971) and FAO/CEEMAT (1972) and has since been widely quoted as being authoritative. Goe and McDowell (1980) accepted the CEEMAT figures and went on to quote figures from the United States illustrating that achieved work rates with teams of 4–12 horses were not directly proportional to the numbers of horses used, and often the same amount of work could be achieved with five horses as with six. Reh (1982) presented a table in which he suggests that multiple hitching of donkeys might lead to reduced working capacities of 10–28% per animal, relative to the capacity of a single animal.

There appears to be some confusion as to what exactly is being 'lost' through this widely quoted 7.5% reduction. In different cases the figure has referred to assumed losses in 'efficiency,' 'draught force' and 'sustained work rate.' Using an experimental treadmill, Lawrence (1983) measured the work done per unit of energy expended for Brahmans working with single and double yokes, and found no significant differences between the yokes in terms of net efficiency.

It would seem that the apparent 'losses' of multiple hitching should not be too much of a cause for concern. Under field conditions, any negative effects of using several animals may well be offset by positive benefits such as mutual encouragement between the animals and the potential to achieve sustained or rapid work. The graphs used to illustrate the work and power output of single animals and pairs (Fig. 2) are also relevant to the use of multiple teams. If one pair of animals can cope with a draught at normal walking speed, coupling an extra team will have no effect in the short term. However, an extra team should allow an implement with even higher draught to be pulled at normal walking speed. The use of more animals per implement should allow working speeds to be maintained for longer periods each day or each week.

The use of multiple teams of animals can lead to problems in manoeuvring and control, and in areas with small fields, if people and implements are available, the use of several small teams may be preferable to one large team. Nevertheless large teams may be appropriate in areas with large fields where operations require high draught power and where animals are plentiful relative to labour and equipment.

Full-Collars and Three-Pad Harnesses

Although it is common for people to advocate that cattle should be harnessed with collars, harnessing collars are seldom used in the tropics. In Europe, collars for horses spread rapidly after the 11th century, and for several hundred years in Europe horses were harnessed with full collars for heavy work and with breastbands for lighter work. As the horse collar spread, so collars were developed for use with oxen. Ox collars were adopted in some localities in Europe (Steinmetz 1936), but they were never employed to the same extent as horse collars. In Europe head yokes, withers yokes, ox-collars and flexible harnesses coexisted for centuries without one clearly dominant oxen harnessing system emerging. More recently ox-yokes and collars coexisted in North America.

The three-pad collar harness for oxen developed in Europe this century was an attempt to produce a harness that would be more comfortable and efficient than a yoke yet cheaper than a collar (Wenger 1938; FSERT undated; Micuta 1985). The three-pad harness apparently spread quite rapidly in certain areas, and is still used to a very limited extent in parts of Switzerland and Germany. The harness comprises two wooden hames, hinged by leather straps at the top, and joined by a removable chain at the bottom (Fig. 1D). The hames are shaped to exactly match the contours of the animal. The shoulders of the animal are protected from direct contact with the hames by two pads, traditionally made of leather stuffed with animal hair, but more recently made from canvas or sack cloth. The third pad is attached to the upper strap which rests on the withers.

Many authors have highlighted the advantages of the three-pad harness in increasing the surface area of contact, lowering the angle of pull and increasing the comfort of the animal (Hopfen 1969; Barton et al. 1982; Micuta 1985; Dibbits 1986). However, three-pad harnesses are much more expensive to make than yokes, and are more complicated to fit and use.

Collars and three-pad harnesses have been assessed in many African countries, but have not been adopted by farmers to any significant extent. Recent artisanal training schemes in Kenya and Zambia have shown that it is feasible to make such harnesses at the village level (Dibbits 1985). However, such initiatives have not yet demonstrated that the technology can be sustained by farmers purchasing the harnesses from the artisans.

Tyre Collars and Flexible Harnesses

Full collars and three-pad harnesses are expensive to make, but collars for cattle and buffalo can also be made from old car or motorcycle tyres. These have been evaluated in Botswana (Froese 1980), Scotland (Lawrence 1983, 1987), Malaysia (Kehoe and Chan 1987) and Thailand (Van Koeverden 1987). Tyre collars have some of the advantages of more conventional collars (low hitch point, large surface area for applying work) while being substantially cheaper. However, since they have no wooden hames, they distort more easily than three-pad harnesses, causing the effective surface area to be reduced when the collar is under strain. There are also reports of discomfort caused by the attachment ropes and the materials used to join the tyre sections (wire or bolts). Kehoe and Chan (1987) found that tyre collars became uncomfortable to buffaloes if they became hot, and so they recommended they only be used in shaded conditions, such as beneath oilpalm trees. Although tyre collars have been found acceptable in on-station trials, there has been little adoption by farmers.

Another system designed for single, or independently hitched animals is the flexible harness. In its simplest form this operates like a single withers yoke made of flexible material such as leather, tyre rubber, sacking or webbing, to which the traces are attached. In order to prevent slippage and allow forces to be spread, a breastband may be attached, as may be a series of back straps and girth straps. Flexible harnesses held in place by a series of leather straps were used with cattle in Europe, and have been experimentally evaluated in Zimbabwe (Barwell and Ayre 1982) and Malaysia (Kehoe and Chan 1987). The flexible harness has some of the advantages of collars (low hitch point, large surface area) and also some of the disadvantages (more complicated to fit and use than a yoke). To date there has been no significant farmer adoption of such harnesses in the tropics.

Collar-Type Yokes

In some Mediterranean countries equines have been yoked together with a traditional design of withers yoke that has padded descending processes designed to allow the animals to push from their shoulders as well as their withers. Comparable collar-yokes designed for oxen have been developed in India (Vaugh 1945; Varshney et al. 1982) and Bangladesh (Hussain et al. 1980), and many similar designs have been tested in Africa. A similar concept was used in the development of the 'Allahabad' yoke in India, which is not unlike a pair of three-pad harnesses linked with a metal yoke (Swamy-Rao 1964; Ayre 1982). Collar-type yokes combine some of the advantages and disadvantages of collars and yokes. Collar yokes do not require independent hitching arrangements, which can be both beneficial (no need for traces and swingle trees) and disadvantageous (the rigidity of yokes is sometimes criticised for causing discomfort and restricting free movement). The hitching height of collar yokes is often intermediate between that of a traditional withers yoke and a full collar or three-pad harness.

Simple collar yokes appear to offer increased comfort through larger contact area and padding without a great increase in cost or complexity (although it should be noted that the Allahabad yoke was significantly more expensive and complicated than a traditional yoke). Some prototypes have performed favourably in on-station trials, although it should be mentioned that in trials in India in the 1940s, an 'improved' collar-type yoke performed significantly worse than all traditional yoking designs evaluated (Vaugh 1945). Nevertheless recent farmer adopton of collar yokes has been minimal. Indeed some designs that were initially hailed as important breakthroughs in harnessing research (such as the Allahabad yoke) are actually no longer used even on the research stations where they were developed.

Merits and Demerits of Collars

There have been many claims about the apparent efficiency of collars and three-pad harnesses for oxen. It has been suggested that the use of three-pad harnesses could double the draught power available in Botswana (Orev 1977). Micuta (1985) observed 'The significant advantages of using a collar harness rather than a yoke are universally recognised. In 1920 Ringlemann established that an ox equipped with a collar could accomplish the same amount of work as two oxen attached to a yoke.' As pointed out, this statement could be true for light work, but it is most unlikely to apply to heavy work; such comparisons of yoked pairs and single harnesses tend to confuse the effects of single vs double harnessing with those of collar vs yoke.

Several authors (e.g. Vietmeyer 1982; Micuta 1985) have referred to the work of Garner (1957) in Thailand to support the argument that bovine collars can increase the efficiency of working animals by 50–70%. In fact Garner had simply run some tests in which a few buffaloes were harnessed with yokes, collars and breastbands and measurements were taken of the maximum sledge weight they would pull and the time required to pull a 340-kg sledge along a 500-m track. In the limited tests, the breastband performed best, followed by the collar and the yoke. No statistical analysis was performed, but percentage differences were presented. Based on the time required to pull the sledge, the computed power output was 390 W with a single withers yoke, 580 W with a collar and 660 W with a breastband, representing *relative* percentage increases of 48 and 70% for the collar and breastband respectively. Garner noted that his statistically unreplicated tests were 'not assumed to be conclusive due to the limited trials,' and he considered 'more work should be done under actual field conditions.' Unfortunately Garner's own caution has often been ignored and, through repeated citations, his figures have become authoritative. Garner's percentage figures have even been ascribed to other workers in this field. For example, despite the fact that he did not claim to have carried out objective experimental work himself, Micuta has subsequently been credited with demonstrating that collars increase pulling power by '50–100%' (de Vries 1986). Such reports in agricultural magazines and newsletters have given many people without access to the primary sources the impression that the dramatic efficiency claims for bovine collars have been thoroughly proven. However, such objective experimental evidence as has been obtained is less convincing.

Swamy-Rao (1964) undertook more replicated research on harnessing on a research station in India. His trials involved the taking of 50 000 dynamometer readings and during the tests the pair of bullocks covered a total of 1400 km under a variety of work schedules (Ayre 1981, 1982). Detailed comparisons were made of single or double bovine collars of the innovative but expensive Allahabad design (Fig. 1G) with single back harnesses and traditional double withers yokes. During sledge-pulling and plough trials, oxen harnessed with withers yokes worked at a rate of 570–1030 W while similar oxen with the collar-type yoke had a power output of 670–1310 W. Oxen harnessed with the back saddle had an output of 450–960 W in comparison with 540–960 W for the single collar-type yoke. Since the mean draught (implement resistance) was not constant within trials, it is difficult to make direct comparisons between these figures, but the higher work output was related to higher average walking speed. In some trials the back yoke outperformed the single collar-type yoke, but in all trials between the double-yoke systems the collar-type yoke appeared to give better results, and it was concluded that the Allahabad collar-type yoke resulted in 14% more power and allowed animals to work 30% longer without major power loss. Its estimated cost of about three times the price of the traditional yoke should have been recovered through increased farm income in 2 years on a holding of about 3.5 ha (Ayre 1981, 1982).

In more recent replicated on-station trials in India, the Allahabad yoke was found to be inferior to two traditional yokes, and superior to two others. The basis for this selection was the degree of physiological stress (rise in temperature, pulse and respiration) suffered by the animals (Varshney et al. 1982). In recent trials in Malawi (repeated, but not statistically analysed) work performance with an Allahabad yoke seldom reached that of head yokes or withers yokes. The trials, which involved oxen pulling logs, were stopped when the pressure pads of the Allahabad yoke started to cause skin abrasions (M. Hawkes, pers. comm. 1989).

In replicated experiments in a controlled but unnatural environment in Edinburgh, an ergometer and gas analyser were used to determine the ratio of work accomplished to energy expended for some buffaloes and Brahman cattle fitted with different harnessing systems (Lawrence 1983). Buffaloes with withers yokes worked at 35.4% ($\pm$1.03) net efficiency, while those with collars worked at 38.8% ($\pm$1.30). Under similar conditions Brahman cattle with withers yokes worked at 28.9% ($\pm$0.68) efficiency, while those with collars worked at 31.1% ($\pm$0.89). This indicated that collars improved the net efficiency of work by about 3%, a figure that was just statistically significant ($P \approx 0.05$) (Lawrence 1983). Clearly this figure of a 3% improvement in recorded net efficiency is well below claims of high percentage improvements in efficiency made by authors working under less controlled conditions. One reason is that Lawrence's percentages refer to the calculated efficiencies of each yoking system (work done relative to actual energy expended over that normally dissipated when walking without a load). The increase of three percentage points (from 35 to 38%) in the recorded net efficiency of the collars in comparison with withers yokes represented a 7–9% *relative* improvement of collars over yokes.

In field trials in Burundi comparable statistically significant increases in net efficiency of 1–2% were recorded (Barton 1985). However Barton, who had previously advocated the use of three-pad harnesses (Barton et al. 1982) concluded that bovine collars were unlikely to be adopted in developing countries, as such modest increases were unlikely to justify their cost and complexity compared with yokes.

In trials in Mexico, Céspedes (1984) was unable to detect significant differences between different yokes and collars in either applied force or speed of movement. In previous work in Bolivia, the same author had observed higher power output from oxen fitted with forehead yokes and collars than with withers yokes (Céspedes 1981). It was not possible to determine the precise reasons for the discrepancy between the two trials, but it appeared that the Mexican oxen were so large (500–780 kg) they were able to draw the implements at normal walking speed with any harness (Sims 1987).

The experimental and anecdotal evidence is not entirely consistent, but it does suggest bovine collars may well be intrinsically more efficient than head yokes and withers yokes. However, there seems no hard evidence to support the very dramatic claims often made for them. Bovine collars can be used singly or doubly but this should not be allowed to confuse the argument as both shoulder and withers yokes can be used singly and can also be used in independent hitching arrangements. If correctly matched and fitted, bovine collars may be more comfortable to the animal, but it is arguable that a poorly made collar is at least as uncomfortable as a poor yoke. While enthusiasts have developed bovine collars at research stations and in small projects in many countries in Africa, Asia and Latin America in the past 30 years (Garner 1957; Barton 1985; Dibbits 1985; Heifer 1985; Pragasam 1987; Kehoe and Chan 1987), there seem to be no reports of sustained farmer adoption following demonstrations. Perhaps farmers consider that the cost and complexity of collars for cattle outweigh their apparent advantages.

Animal Comfort

In any locality there are likely to be examples of well-finished and correctly fitted harnesses, and others that cause discomfort. The potential for improvement is therefore enormous, and some authors have argued that their favourite yoking system could halve the number of animals needed for a particular operation; this (it has been suggested) would have the same impact as either increasing the number of working cattle by 20–50% or of releasing large quantities of additional animal feed. Such claims are almost certainly spurious.

Controlled experimental work at the University of Edinburgh demonstrated that while there was not a great difference between the technical efficiency of various designs of yokes and collars, animals were certainly more willing to work if the harnessing system was comfortable (Lawrence 1983). The implication is that while the metabolic energy required to perform an operation is broadly comparable whichever harnessing system is employed, the nervous energy required from both animal and human may be much greater with an uncomfortable yoke. Animals need more encouragement and goading if their harness is uncomfortable, and the discomfort of the animal can be matched by the frustration of the farmer.

The paper of Varshney et al. (1982) mentioned above provides some interesting food for thought relating to yoke design and animal comfort. The researchers compared five yoke types by making pairs of animals pull against a loading drum for 75 m following which the animals' temperature, pulse and respiration rate were recorded. Yokes were selected on the basis of the degree of apparent physiological stress (rise in temperature, pulse and respiration) suffered by the animals. It was concluded that the worst yokes, from the point of view of the animal, were those that led to the highest rises in animal temperature, pulse and respiration. However, from the data presented (Fig. 3), it would appear that such stress may well have been associated with quicker walking speeds and faster

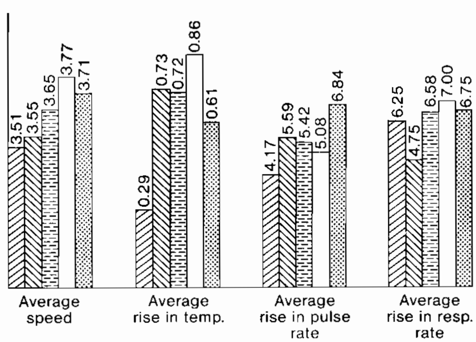

Fig. 3. Summary of mean results of harnessing trials of Varshney et al. (1982). The walking speed (km/hour) was measured while animals were pulling a loading drum and the subsequent rise in animal temperature (°C), pulse (beats/min) and respiration (breaths/min) were taken after work. The central bar (with vertical stripes) for each parameter represented a steel collar yoke, while the others were local variations of wooden withers yokes. The authors' order of preference of the yokes, based on low animal stress, was (from left) 2, 1 and 3 followed by 4 and 5.

rates of work. Could it be that the rejected yokes were actually the most comfortable and therefore allowed the animals to work at a faster rate? With such an interpretation, the yokes acclaimed for not having caused the animals stress might actually have been the most *uncomfortable*, which might explain the animal's slower speed, slower work rate and consequential lower rises in temperature, respiration and pulse.

Overview of Research

Several studies on yoking systems in Europe have been largely descriptive (Delamarre 1969; de Oliveira et al. 1973). Similar studies in developing countries could be valuable in providing a geographical or historical perspective, and could be particularly useful if combined with farmer opinions on the relative merits of different systems.

Some other harnessing research has been in the form of comparative assessment of two or more harnessing systems. A few of these should be dismissed from the point of view of research as well-meaning, but spurious, being designed in the form of demonstrations to *prove* that a 'new' or 'improved' design was better than an existing design. Commonly such studies have confused two or more parameters but have nevertheless tried to present their results in a semi-scientific form. Unless there has been some form of replication, randomisation, control and objective measurements, then results presented as percentage improvements in 'efficiency' should naturally be treated with great caution. Nevertheless provided they are acknowledged as such, evaluation trials based primarily on subjective judgments rather than measurements can be extremely useful as a means for assessing options (e.g. Froese 1980).

Replicated trials involving the measurement of force (dynamometer readings), time, distance travelled, speed and work achieved have been reported from: India by Vaugh (1945), Swamy-Rao (1964) and Varshney et al. (1982), Bangladesh by Hussain et al. (1980) and Barton (1988), Bolivia by Céspedes (1981), Burundi by Barton (1985), Costa Rica by Lawrence and Pearson (1985), Mexico by Céspedes (1984), Morocco by Bansal et al. (1989), Thailand by Garner (1957), the United Kingdom by Barton (1985) and the United States by Kivikko (1987). In addition, trials involving the detailed recording of animals' physiological responses to different yokes have been recorded for buffaloes and Brahman oxen walking on treadmills (Lawrence 1983; Islam 1985). Some of the findings of these various trials have been discussed by Duchenne (1984), Matthews (1986), Sims (1987) and Starkey (1989).

Starkey (1989) attempted to summarise many of the conclusions of these research programs in five points:

(1) Firstly, the various improved forms of padded yokes and collars did seem to have allowed greater work relative to *some* traditional designs. This may be because comfortable harnesses made animals more willing to walk faster and/or pull harder.
(2) Secondly, some quite high apparent benefits in technical efficiency did not generally lead to major differences in achieved on-farm work, such as the area cultivated in a week.
(3) Thirdly, when a large range of yokes had been tested there were generally examples of *alternative* traditional designs that have been much cheaper than the improved designs, and which have been of comparable efficiency (in some trials — such as those of Vaugh 1945; Hussain et al. 1980; and Varshney et al. 1982 — some traditional harnesses have out-performed improved designs).
(4) Fourthly, many improved harnessing systems appear to have been significantly more expensive or more complicated than traditional yokes.
(5) Finally, despite a detailed review of the literature and personal communications with many of the workers in this field, there seem to be no recorded cases where the various improved designs mentioned in research reports have been widely adopted by farmers.

Recent advances in electronics have made it possible to log large quantities of information as animals work, including physiological parameters (temperature, heart rate, respiration rate), walking characteristics (speed, walking rhythm, distance), workloads (forces, angles) and the external weather conditions (sun, temperature, wind) and to process the data rapidly using computers (Lawrence and Pearson 1985; Matthews and Kemp 1985; Lawrence 1987; O'Neill et al. 1987; Kemp 1987). Such data collection should be able to provide detailed comparisons of different yoking types and if combined with appropriate analyses (and consideration of farmer opinion) may be able to assist in the identification of low-cost and simple means of increasing the efficiency of yokes.

Matthews (1986) suggested that the development returns from small-scale, ad hoc harnessing research programs are likely to be minimal. It could be added that returns to any harnessing program may depend more on its relevance to the needs of particular farmers than the technology employed.

Conclusions

While scientists and development workers are clearly worried by existing harnessing systems, and it is agreed that there is much room for improvement, there is little to suggest that farmers regard harnessing as a crucial limiting factor. As with any technology harnessing designs are likely to involve compromises between technical excellence, economic cost and social considerations (including fashion). While it appears that independently hitched collar type harnesses may be the most technically efficient, they are also generally the most expensive and complicated to use. Differences in efficiency between a well-padded and a poorly padded local yoke or a well fitted and a badly fitted harness may well be as great as differences between the harnessing systems themselves. It seems likely that in the foreseeable future the main harnessing types will continue to be the double or single withers yoke and the double head yoke for bovines and the breastband for equines. In the short term the most likely improvements will be very simple changes in contouring and padding. In many areas improvements in overall harnessing efficiency are more likely to come from encouraging the correct use of farmer-proven designs from within a region rather than from promoting innovations.

Given the apparent confusion in the literature as to what constitutes efficiency in yokes, there would seem to be much scope for some thorough research, using data logging techniques to establish the mechanical and physiological attributes of yokes in different conditions, and on-farm comparisons to link these data with farmer perceptions. The research should aim to clearly distinguish between those separate elements that are often confused (single, double or multiple animals; rigid or flexible linkages; combined or independent hitching systems). It would be hoped that such a study should clarify the relative importance of the elements often claimed to be crucial (such as contact surface area, angle of pull and weight) and it might provide new insights on how design and construction material can affect the efficiency of energy transmission and load dampening.

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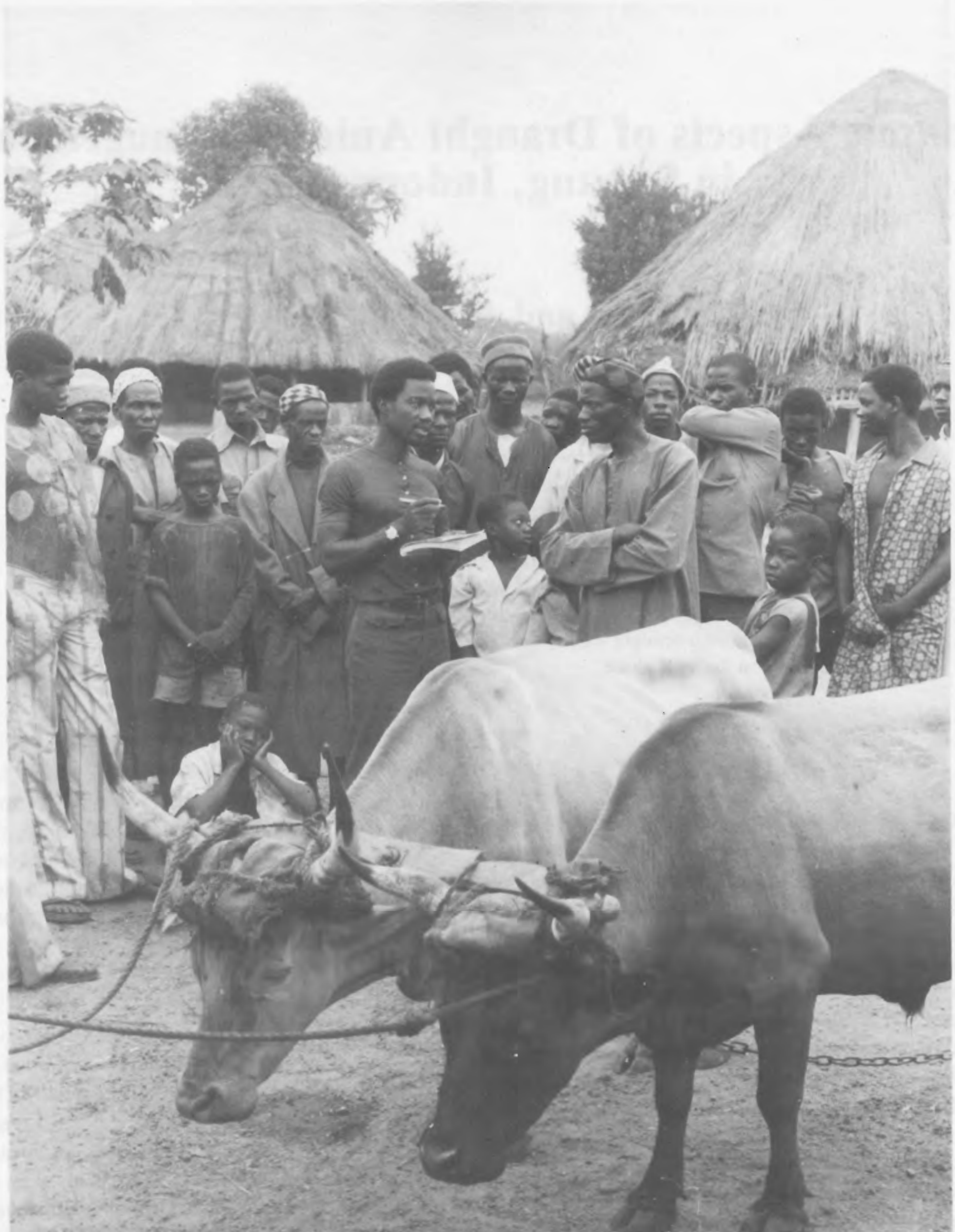

Section 8
Economics of Draught Animal Power

Economic Aspects of Draught Animal Management in Subang, Indonesia

John Perkins* and Armiadi Semali**

Abstract

In many areas, draught animal power will be one competitor in a stable, competitive market for land preparation. Increasing the efficiency of draught will reduce the number of draught-capable animals that farmers are willing to retain on their farms. However, increasing efficiencies related to the nondraught values of animals will increase the number of draught-capable animals retained. A study of 10-year inventories for cattle and buffalo in village households at Subang, Indonesia, showed that turnover of animals was more rapid than originally anticipated, indicating farmers' strong awareness of these nondraught values. This implies that research which links production with draught would have greater impact and acceptability than research which concentrates on draught alone.

Introduction

ONE common goal of draught animal power (DAP) research is to make draught animals a more attractive proposition for smallholder farmers. It is often assumed that, if DAP can be made easier to manage or cheaper to utilise, more farmers will keep draught animals and the total stock of large ruminants will increase, with beneficial side-effects on the supply of related animal products. It is our contention that, in many areas, the reverse will occur — increasing the efficiency of the DAP enterprise will lead to some reduction in the total number of cattle and buffalo retained on farms. This reduction will come about through the normal operations of a competitive market for land preparation. There is nothing wrong with a reduction in draught animal numbers as such reductions may reflect an increased efficiency in the use of resources. However, it is unlikely to be the result that policymakers expected or desired. The first part of this paper examines the line of thought that leads to this conclusion, and the implications for the future direction of research into DAP. The second part summarises initial results from a study of turnover rates for cattle and buffalo in two villages in Subang, Indonesia. An assumption is made that land preparation remains the major use of DAP.

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Value of Animals to a Farmer

The impetus for this study arose from consideration of the linkages between the market for land preparation and the market for meat. The authors were involved in the economics component of a multidisciplinary research program investigating DAP in Indonesia. One aim was to establish some economic expression of farmers' utilisation of draught animals, to help determine where the most profitable areas of research might lie. It became quickly apparent that any economic assessment of the draught-related functions of cattle and buffalo could not be easily separated from the other benefits (and costs) involved.

The multiplicity of functions provided by large ruminants has been amply covered by a number of authors (e.g. McDowell 1981). Most of these functions can be collapsed into two major categories which we have loosely labelled as 'muscle' and 'meat' respectively. A farmer can use his draught-capable animals to prepare his own land and save the money that would be needed to rent-in power from another supplier. He can also earn income by renting-out these animals to prepare land for other farmers. The nondraught values include retaining animals as a form of savings or wealth, selling them to raise income and, in the case of females, obtaining calves that can be used as replacement animals or reared and sold.

The draught and nondraught values are closely intertwined. However the nondraught values can be concentrated, for convenience, into one variable: the value obtained at sale. Regardless of utilisation for draught purposes, cattle and buffalo will always have a sale value, and this derives from their eventual slaughter for meat. Many farmers in Indonesia do not specifically rear their large ruminants for meat production, and there is usually a chain of sales during any animal's lifetime. However, there is always a capital value for the animal — young or old — and this value is dependent upon eventual slaughter.

An additional, and most important, factor is farmers' assessments of the comparative values of these animals. To rear cattle or buffalo involves the use of resources and incurs costs. The animal enterprise must compete with other enterprises available to the farm household, including cropping and nonagricultural activities. Farmers will select enterprises with regard to the resources available to the household and the perceived 'profitability' of each enterprise that can use these resources. The final expression of the comparative value of large ruminants (including both draught and nondraught values) is the number of farmers that choose to rear animals and the number of animals that each farmer rears.

The Market for Power

At the inception of the DAP project, the economists elected to adopt an umbrella hypothesis for testing, 'Farmers are generally efficient in the allocation of their resources, including DAP.' This approach was chosen because there was no a priori evidence to suggest that farmers are inefficient — in terms of guiding research, there was no obvious hole to plug. In addition, the approach also placed DAP firmly within the context of the complete farming system, as one interactive component among many.

Study sites in the Subang District of West Java were selected, in cooperation with the farming systems and nutrition researchers in the project. Initial observations and informal discussions with farmers gradually led to some development of this approach. Firstly, there did not appear to be any absolute shortage of power for land preparation. The most limiting constraint appeared to be water, either rain or irrigation. Fields did not remain untilled if sufficient water was available. Secondly, farmers did not nominate a need for more *draught* animals. They certainly expressed a wish for more cattle and buffalo, as these represent an increase in wealth and potential income, but a similar wish would probably be expressed for any capital asset, and irrigated land, *sawah*, would be the first choice for most.

Their actual preference for large ruminants could be indicated by the numbers to be found at the study sites — some 15% of households reared cattle or buffalo and 85% reared neither (Santoso et al. 1987; Sumanto et al. 1987). Yet most land preparation for irrigated rice production was done by cattle or buffalo in preference to hand labour or tractors. It appeared that most farmers saw greater advantage in renting-in another farmer's animals and avoiding the expense and effort of rearing.

A general model was now developing: the large ruminant system was influenced by market pressures. In the case of Subang farmers, two major markets would dictate returns to cattle and buffalo rearers. The market for land preparation would determine returns from draught usage and the market for sale (ultimately influenced by the demand for meat) would determine the nondraught values. The rearer could choose to operate in one market or both. Most females were raised for draught, calves and sale; most male calves are sold relatively early despite their draught capability. This is confirmed by the dominance of females (and mature females, in particular) in Subang (Santoso et al. 1987), a situation which is common throughout Indonesia.

The market for power was of particular interest. We felt that we were observing a balanced, stable and competitive market for land preparation, in which farmers were both price-conscious and price-responsive as potential users and providers of power. The main features of the market can be summarised as follows:

- the major competitors are DAP, human labour and tractors. All are used in Subang, although tractors have a relatively minor role and draught animals dominate at present;

- the farmers' unit of comparison is the total cost of land preparation per unit area;
- farmers can choose to rent any power source (in any combination) or use household resources (in any combination). In practice, these combinations can be quite complex. It is very common to find one farmer's land prepared by family labour, rented labour and rented draught animals. It is not uncommon to find a draught animal rearer renting-in DAP from another farmer, presumably to hasten his own land preparation (Basuno, pers. comm.);
- efficiency of land preparation by any combination is equal and has no effect on yield;
- prices are determined by competitive market pressures and draught animal rearers will respond to price changes, increasing draught animal numbers if the rental price rises (e.g. more land can be cultivated because of an increase in the area irrigated), and reducing numbers if the price falls (e.g. agricultural land is lost through urban expansion).

Now assume that a technological change is introduced into this market for land preparation. For the purpose of illustration, imagine that an area of 200 ha is serviced by a blend of power sources, with the greatest input coming from 100 draught animals. A technical change is made to the draught system that increases field efficiency by 20%. This increase will mean that only 80 animals will be needed where 100 were used before: 20 animals have become 'superfluous.' What will happen? Many scenarios can be developed. Three are listed below.

(1) The number of animals will be reduced and each animal will cover 20% more area. Providers will receive 20% more income as the rental price will remain the same.

(2) The number of animals will remain unchanged and each animal will prepare the same area, for 20% less effort. Providers' income remains unchanged.

(3) The number of animals is increased. Each animal prepares less ground than before. Providers' income will fall.

The third scenario has been included as many people expect that an increase in efficiency will automatically make an enterprise more attractive. However, if the market is limited — in this example, only 200 ha of land is available for tillage — these gains will not be available to everyone. The third scenario is, thus, the least likely to occur. The most likely outcome will fall somewhere between Scenario 1 and Scenario 2: some draught animals will be removed from the market. The final result will develop over a period of time. One or two innovative farmers will be the initial adopters. They will receive a 20% income benefit and more farmers will follow their example. The less efficient draught animal rearers will be squeezed from the market.

What will be the effect on the total number of animals reared by farmers? This will be a result of both the draught and nondraught values. No changes have been made to the efficiencies of raising and maintaining animals for sale. In this case, therefore, the total number of animals will fall by the number of draught animals that are displaced from the tillage market. As most of the displaced animals will be female, there will be an additional 'loss' of future calves.

Is the analysis valid? We believe that there are many historical examples that underline the point. The almost total displacement of DAP by mechanical power in high-income countries is a proven case; of associated interest is the increased total cattle herd maintained in these countries specifically for the production of meat. A more appropriate example comes from Lombok Island in Indonesia. In one area of this island farmers can select the traditional *merancah* technique of land preparation (trampling by a group of buffaloes) or DAP implements used with pairs of Bali cattle. The costs of either technique are very similar on a per hectare basis but the *merancah* technique is gradually being supplanted, as the off-field costs of maintaining large buffalo herds make them noncompetitive as an agricultural enterprise. In other words, *merancah* is less cost-effective — in total — than implements and produces a lower net return to farmers than competitive enterprises. The *merancah* herds are now smaller than in previous years and their efforts within the *sawah* are increasingly supplemented by the use of some input from DAP cattle systems. It is likely that, in the not-too-distant future, the *merancah* system will no longer be used in Lombok, displaced by a better competitor (Perkins and Sarwono 1987).

Implications for DAP Research Strategies

The analysis suggests that improving draught efficiency will lead to a reduction in the number of draught animals when the draught systems operate under competitive market conditions. This may be discomfiting for policymakers, as most expect research to provide positive results and a reduction in animal numbers is not usually regarded as a positive outcome. However, our analysis at this point was not pessimistic. A number of conclusions could be made. Firstly, DAP research is still completely justifiable as it may increase the efficiency of those households that provide draught animals to the rental market and, thus, increase their income. In addition, it may increase the total efficiency of the whole farming system and provide a better allocation of available resources.

Secondly, if the objective is to increase the total number of animals retained on farms then nondraught values must receive due attention. If the net returns from cattle and buffalo cannot compete with crops, other farm activities or activities off the farm, there is no incentive to increase the number of animals maintained.

An acceptable strategy for many farmers would be to increase the efficiency of meat production from large ruminants and look upon their draught capability as a welcome adjunct and the renting-out of these animals as an additional source of income.

Long-Term Inventory Study

The argument outlined above indicated a need to improve our understanding of farmers' management strategies for cattle and buffalo. Some aspects of these strategies are known; for example, farmers prefer to retain females. Other aspects are assumed: farmers wish to retain animals for as long as possible to conserve an important capital asset. Our initial interpretation of the general strategy of Subang cattle and buffalo farmers would include the following:

(1) preference for female animals;

(2) long retention, particularly of fertile females;

(3) long calving intervals;

(4) infrequent sales;

(5) infrequent purchases, due to the high capital cost;

(6) high labour inputs associated with cut-and-carry feeding and supervised grazing.

The general model could be characterised as 'low vigour' — slow turnover, limited output, high labour. It was important that this model be challenged as it would form the basis for guiding research into the production (rather than draught) values of animals.

A 10-year inventory was conducted among all current cattle or buffalo rearers in four villages at the survey sites. The objective was to assess the turnover rate of livestock: were typical strategies based on long retention periods for animals? The preliminary results that follow come from two of the four villages studied, as our aim, at this stage, was to determine the most appropriate way to handle the data. All farmers were asked to recall their large ruminant inventories from 1978 to 1988. A 10-year period was deemed appropriate as most rearers only manage 2–4 animals at any time. The data presented do not distinguish between cattle and buffalo.

Average Turnover for Individual Farms

The scatter-plot in Fig. 1 summarises the turnover for each of the 126 participating farms in the two villages. This is done by plotting Total Animal Years (TAY) against Total Entries (TE), where:

i) TAY is the total number of animals reared on the farm in 1978–88, multiplied by the number of years that each animal was on the farm; and

ii) TE is the total number of animals entering the farm inventory 1978–88, either by being on the farm in 1978 or through birth, purchase, sharing-in, exchanging-in or some other means of entry.

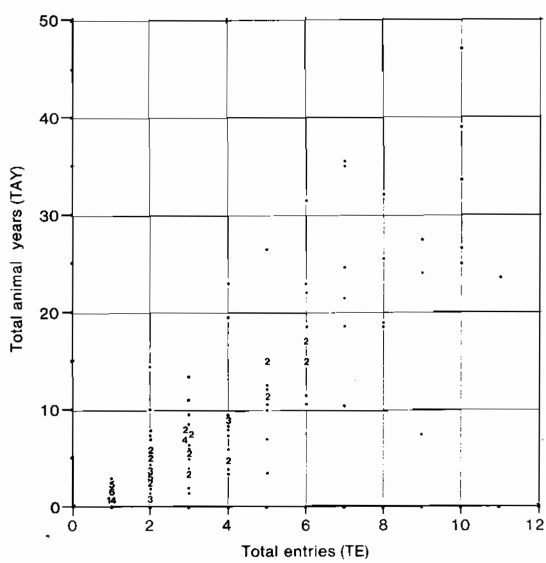

Fig. 1. Relationship of TAY and TE for 126 farms in two Subang villages, Indonesia.

If animals were retained for long periods on farms because of their capital (and draught) values to the farmer, then one would expect to find a major grouping in the upper or northeastern corner of the figure — high TAY. In fact, there was a fairly general scatter of relationships apart from a strong clustering in the southwestern corner of the figure, indicating that many farms reared only a few animals during 1978–88 and retained them for only a short period. Strategies were more vigorous than anticipated.

This is confirmed in Fig. 2 which classifies farms according to the turnover rate obtained from TAY/TE. Most farms retain males for less than 2 years

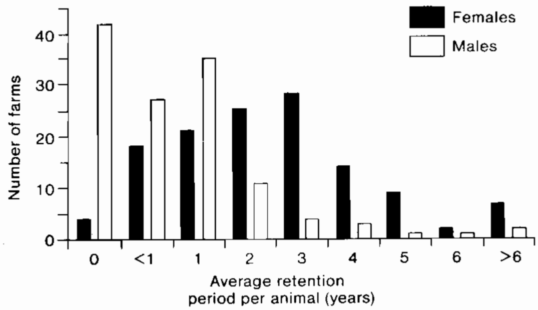

Fig. 2. Average retention period, in years, for large ruminants in two Subang villages.

and females for up to 4 years, with a small group retaining females for more than 7 years. Of particular interest is the large number of farms that choose not to raise males at all.

Average Retention Periods for Animals

One problem posed by any inventory is that it includes animals with an indefinite history — some were on the farm when the inventory commenced in 1978, others were still on the farm when the inventory was closed in 1988. Such animals have been excluded from the data used for Fig. 3, which summarises the period of retention on farms for animals with complete records, i.e. both entry and exit are recorded. This does mean that some long-staying females are excluded but the previous section had indicated that these form a relatively small, but important, proportion of the total records. Figure 3 confirms that most animals, male or female, remain on-farm for relatively short periods. Females tend to be held slightly longer: the average turnover period was 2.9 years for females and 1.8 years for males overall. However, the median class for both males and females was 1 year. This challenges our assumption that females will be retained for their

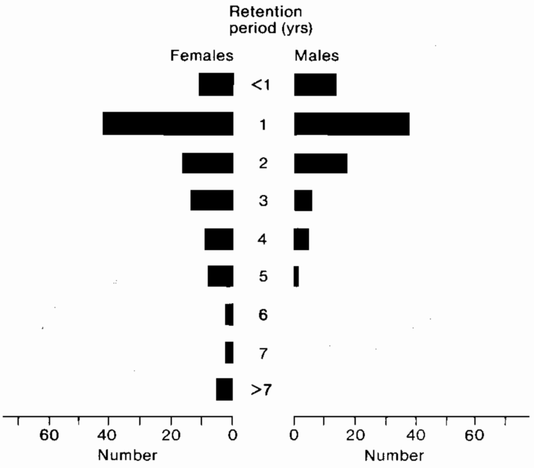

Fig. 3. Period of retention for animals with complete records (excludes animals already on-farm in 1978, or on-farm in 1988).

potential breeding value: farmers are apparently willing to release females.

Methods of Entry and Exit to the Inventory

Figure 3 shows how animals arrived on the farms, excluding those present in 1978; Fig. 4 summarises how animals left the farms. The entry data indicates that birth was the most common mode of entry but purchase, exchange, sharing and other arrangements accounted for almost 40% of total additions to stock. The preference for females is

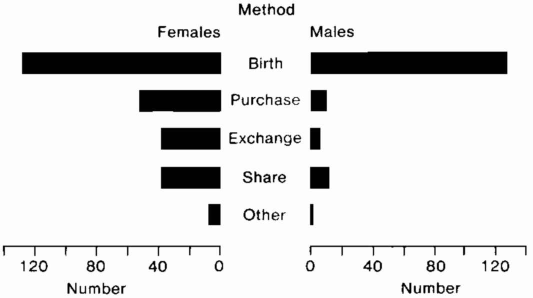

Fig. 4. Method of entry to the inventory, 1978–88 (excludes animals present on the farms in 1978).

again underlined by the data for entries other than birth: given the choice, farmers select females. The high number of animals exchanged was a real surprise. In two extreme cases, animals (presumably calves) were each exchanged for goats.

Figure 5 shows that economic factors — sale, exchange or share — accounted for most exits from the inventory. Relatively few animals died on-farm

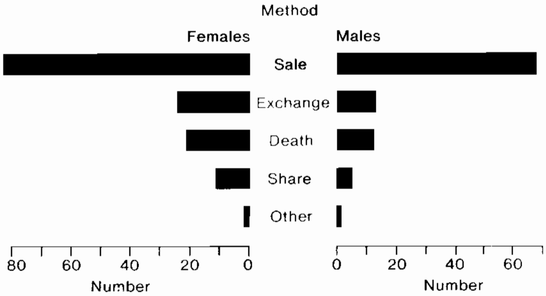

Fig. 5. Method of exit from the inventory, 1978–88 (excludes animals still on the farms in 1988).

and most of those were calves. Only two animals were slaughtered for consumption in the 10 years studied.

Conclusions

The inventory study has forced us to reevaluate our informal model of farmers' strategies. The major result was that the average period of retention was much shorter than anticipated. Management was more 'vigorous' than previously assumed. This provides the opportunity to develop and test a range of strategies, e.g.

- There are some farmers who do retain females for a long period and who specialise in renting-out these animals for draught work. They might be interested in reducing the labour involved in feeding the animals and obtaining more calves without overly affecting work capacity.
- There are many farmers who retain animals for relatively short periods and have a history of buying and selling. They might be interested in strategies to decrease this holding period through better feeding and quicker growth.
- There is a large number of farmers who use their animals for tillage but do not see value in maintaining the animals just for that purpose — they will sell or buy draught-capable animals if the opportunity or need arises. They are probably most interested in reducing the costs of maintenance.

Overall, the inventory confirmed one important point — farmers do not keep cattle and buffalo solely for draught work. In fact, we tend to bias our own perception by calling them 'draught animals.' They are not — they are 'draught-capable animals.' If farmers, on average, keep animals for less than 3 years there is little point in putting too much effort into making the animal a draught specialist. A more appropriate strategy is to produce the animals for sale and use them for draught work when needed.

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Draught Animals in National Livestock Planning

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Abstract

Agricultural development planning has been used to the benefit of government-related investment in national development in many developing countries. National plans commonly stress agricultural production including livestock production, yet overlook the critical input of draught animal power (DAP) in agricultural production. Means of integrating DAP into national plans, through additional investigations and modification to project formulation by interrelated agencies within their existing modes of operation, are proposed as a solution.

National Livestock Planning

NATIONAL economic and social development plans have provided a basis for government investment, decision-making and allocation of scarce resources in order to meet agreed development objectives. The success of such plans is variable. It is evident in countries where political stability, an absence of natural disasters, and a phase of international cooperation are present. An example of this is Thailand which has maintained economic development strategies through six 5-year plans focusing on, among other things, infrastructural and industrial development. Despite weaknesses in some plans, the emphasis of increased governmental coordination and the availability of reference documents for foreign loan and aid bodies provided a basis for development decision-making.

Such national plans are commonly compiled by boards or units established in prime ministerial offices or equivalent, and act by interpreting government policy and collating and recommending individual ministry and department budgets and work plans. As a result of the strong agricultural orientation of development programs in most of the developing world, agricultural development plans represent a major component of such national development plans.

Within agricultural development plans, the role of livestock is commonly presented in terms of targets for increased livestock populations, ratios of females to males in cattle and buffalo populations, survival and outputs of quantifiable products such as milk or fibre. The role of DAP in agricultural production and the need to maintain a viable working animal population is seldom acknowledged in these plans.

In mixed agricultural economies, grazing livestock are often raised on poorer lands where the lower income and living standards of the human population may lead to social development programs taking some precedence over economic programs; in such circumstances, the role of DAP will also tend to be overlooked. The common perception that grazing livestock provide competition for scarce agricultural resources in densely populated areas similarly focuses attention away from the essential power input to agriculture provided by such animals.

Such scenarios will be familiar to persons engaged in livestock development. It is encouraging to note that increased attention is now being paid to livestock planning by aid and development financing agencies such as the Australian International Development Assistance Bureau (AIDAB 1987), the Asian Development Bank (ADB 1983), the World

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Bank (1985) and the European Economic Community (EEC 1984). Each of these agencies refers to the role of DAP being understated in previous livestock planning and development. A common theme of providing future assistance to the livestock industry through national livestock planning exists and is typified in the statement of AIDAB (1987) in a review of their livestock projects over the past decade: "Livestock policies are commonly poorly developed and may not reflect appropriate targets and choices for governments. Input to livestock policy and planning is an area where greater assistance from AIDAB could lead to significant and cost effective improvements in livestock development. Such projects should be addressed in an institutional mode involving training and expertise."

National planning may have been less effective in centrally controlled economies such as Vietnam and China due to a failure to include the role of the private sector and its associated incentives in such plans. With the rapid reorientation of Vietnam, the need for informed planning systems is immediate as a means of coordinating the increased government and external inputs to development expected after 1990.

Need for Planning to Include Draught Animals

Inputs to agricultural production include DAP in most developing countries. Research aimed at reducing dependence on DAP or improving its efficiency is of increasing significance yet appears to be only tenuously linked to mainstream decisions concerning agricultural development, which are usually based on agricultural development plans. There is a need to strengthen the linkage between DAP research and national planning, not simply to enhance the likelihood of research results being applied, but to also ensure that the critical role of DAP in the agricultural production system is recognised. It is easy to imagine how policies to increase beef or dairy production could conflict with the need to maintain a sustainable draught animal population.

The role of DAP in agricultural systems has been described elsewhere as one of several critical inputs including land, labour, chemicals, etc. The needs of draught animals in terms of feed, land and labour have also been defined. However, these needs are not usually included in national development plans, a situation which can lead to development plans assuming the use of these resources for other purposes, including nonagricultural uses.

There is a further need to include draught animals in national livestock planning. In cases where development plans focus on the introduction of 'new technology,' existing components of the production system may be assumed to be disappearing and thus not worthy of acknowledgment in such plans. The assumption that reliance on DAP will decrease until it no longer exists is implied in some planners' agenda, especially where development is interpreted to mean pursuit of the same paths followed by western countries such as the USA and Australia. While such an assumption may be seen to be unjustified by concerned persons, the influence of those people may not be sufficient to impact on national development plans. The realisation of the development aid and financing agencies of the need to assist planning provides a means of acknowledging the role of draught animals; suggested means of putting this into practice are presented in this paper.

Current Situation

Many countries (McDowell 1977; Falvey 1981) have long legislated against the slaughter of draught animals below the age of 7–10 years to provide for a sustainable pool of reproducing and working animals. However, such regulations are not usually enforced because of their incompatibility with other demands (e.g. meat products and mechanisation in some areas). While these regulations acknowledge the importance of DAP, they are not flexible and do not arise from a planning process based on an understanding of the dynamics of the agricultural production system.

A dated example of increased awareness of working animals in planning in a developing country is Sri Lanka (MPW Australia 1988). In the National Development Plan for Livestock over the period 1979–83, the Ministry of Rural Industry and Development mentioned the contribution of animals to draught and traction and included plans for the improvement of the livestock sector. Specifically, it was estimated from 1973 figures that, of the 494 307 cattle and 178 038 buffalo in the country, 98 860 and 35 600 pairs of cattle and buffalo would be available for working a maximum area of 140 000 ha; this failed to meet calculated requirements each year by 60%. In addition to this apparent deficiency in numbers of working animals, all cultivation must be carried out within a period of 45 days to benefit from rainfall patterns. The traditional means employed to ease the deficiency of animal power has been the importation of stock from India when foreign exchange was sufficient. While such figures are based on dubious statistics and assumed cultivation rates, this example indicates an attempt made to work with available information as a preliminary stage of livestock planning. The intent of Sri Lanka to effect improved livestock planning can be traced to the current GTZ assistance (MRID-GTZ 1987) to upgrade the Livestock Planning Unit, which addresses the sector through a strategy relating each of the following:

- — dairy development
- — feed resources development
- — product-oriented extension
- — reorientation of state farms
- — promotion of small ruminants
- — monogastric industry promotion
- — draught power development
- — animal breeding
- — marketing (processing and pricing)
- — planning for livestock development.

From such estimates of DAP needs, plans to ensure the supply of animals and equipment can be formulated; nationally funded research programs can also be focused on the country's priority problems relating to DAP.

In the case of Laos-PDR, a country emerging from a period of conflicting development philosophies, the first stage of national livestock planning is based on economic awareness of the importance of the cattle and buffalo resource, and the limited financial and labour resources of the country. Government policy (UNDP 1989) calls for the principal government-funded intervention, vaccination, to be concentrated on cattle and buffalo for export (to neighbouring Thailand) and draught respectively in those provinces where major cattle and buffalo populations exist and where rice cultivation has the greatest potential.

Means of Including DAP in Planning

In order to include planning for an appropriate DAP resource nationally, the responsible agency, usually a Department of Livestock or equivalent, must have a structure oriented to the needs of the industry. Departments of Livestock usually have organisational structures based on western departments of research, extension, veterinary services, etc.; where orientation is to products, divisions of beef, dairy, etc. may exist but seldom is DAP represented per se. The World Bank (1985) review of livestock projects noted that livestock departments are usually outdated and not oriented to the development needs of their countries.

With an appropriate acknowledgment of DAP in livestock departments, collation of information and setting of development objectives and targets in national development plans by planners would allow for the needs of draught animals to be met.

The increased emphasis on DAP by development aid and financing organisations provides a basis for encouraging joint national and foreign teams to conduct planning inputs needed to refine livestock development policy. Coordination of such inputs is well suited to discrete planning activities, and can be managed by either a donor or, preferably, the national government as a discrete contract.

Preparation of specific Terms of Reference will lead to consultancies providing a basis for livestock policy statements, strategies for implementation and recommendations for changes to regulations and incentives if applicable.

Points to be addressed and thus forming part of the Terms of Reference for a Livestock Planner would include:

- — determination of the size, productivity and population trends of the draught animal resource and estimation of its use;
- — estimation of DAP needs at the present time and in 5, 10 and 20 years;
- — preparation of simple descriptive models to predict the land, feed and other resources necessary to sustain these DA populations;
- — separation of DAP needs into regions and determining the role of stock raising as either an adjunct to agricultural production or a separate industry in geographical and/or employment terms;
- — estimation of mechanisation rates as related to DAP and prediction of the categories of agricultural production that will continue to rely on DAP;
- — estimation of the need for DAP in opening up hitherto unused areas for agriculture;
- — definition of trends in agricultural production and other users of DAP;
- — determination of the rate of demand change for other livestock products such as meat and milk;
- — estimation of the degree of compatibility of DAP with the production of other livestock products and the implicit effect on resources needed to maintain the livestock base;

— identification of conflicting objectives introduced by uncontrolled market forces which may require government regulation to meet a national objective such as minimal rural migration;
— assessment of support service inputs required to maintain a healthy and productive national herd for DAP and other livestock products;
— identification of constraints to understanding in any of the above areas, technical limitations and any other needs that can be addressed through DAP and related livestock research programs; and
— presentation of findings in a format suited to policymaking, institutional reorganisation including personnel development programs, formulation of regulations and means of monitoring implementation (for the purposes of regular adjustment of management of the national livestock resource).

The general process of agreed Terms of Reference is utilised beneficially for the preparation of major international finance projects in traditional development fields. The addition of points such as those listed above for DAP would represent a small addition to the workload of project preparation teams, and would lead to an understanding of the critical role of DAP in the crop and livestock subsectors.

Conclusion

Integration of DAP into national development planning is logical and may have been neglected to date as a result of a western orientation to planning. The essential investigations necessary at both macro and microeconomic levels will provide a basis for determining means of protecting or enhancing the DAP resource, in accordance with the needs of agriculture and other users of DAP, while also highlighting any needs for DAP research. An additional benefit from this approach of relevance to DAP researchers would be a coordinated approach to DAP research focusing on identified needs of the country.

Reference to DAP and other livestock products should be included in national project documentation, in the preparation of structural adjustment or program loans and in institutional development components of projects focusing on agricultural planning or livestock planning units of departments of livestock. Resources needed to cover such factors already exist in the teams constituted for such consultancies, and thus only minimal reorganisation of the scope of services should be necessary. With the increased awareness of the ongoing role of DAP in most developing countries, such a logical expansion in project preparation activities should be expected from major development aid and financing agencies in the near future.

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Effect of Government Policies on Draught Livestock Development in Indonesia

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Abstract

Government policies that affect draught livestock development in Indonesia were reviewed. Also studied were past performance and restrictions experienced in the application of these policies, and policies under consideration for future adoption and implementation. The study also sought to develop directions for draught animal power research that would link with policies adopted by the Indonesian government.

Introduction

THE main policies affecting draught livestock are:

(1) budgetary allocations by the government for support of the general objectives of livestock development;

(2) adoption of modern technology for food crops, and agricultural mechanisation in Indonesia;

(3) policies on the development of the draught animal population, output, the intensification program (INTEK), and interregional trade policies.

Budgetary Allocation Policies

From the above points one can see that the expected roles and objectives of the livestock development program are broad and ambitious. One of the problems, of course, is the question whether the livestock subsector will get sufficient financial support, or put another way will the livestock subsector get a balanced priority from the agricultural development planners? The figures in Table 1 show the government budget allocations and gross domestic product (GDP) contributions of the agricultural subsector during the first 3 years of the Fourth Five-Year Development Program. The livestock subsector receives relatively sufficient government budget support. The livestock subsector position has been even better than the food crops and estate subsectors. This is shown by the higher ratios of budget allocation and GDP creation. In absolute terms, the livestock subsector was placed second in the list of groups receiving government support, after the food crop subsector. In relative terms, by taking into account GDP contributions, the livestock subsector is also placed in second rank, but now after the estate subsector. The food crop subsector obtains the lowest budget allocation, based on relative criteria.

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Table 1. Government budgetary allocation as a proportion of sectoral GDP, 1984–86.

Subsector	1984	1985	1986
	%	%	%
Livestock	1.4	1.2	0.7
Fisheries	1.8	1.5	1.0
Estate crops	0.6	0.7	0.4
Food crops	0.5	0.4	0.2

Source: Bureau of Planning, Ministry of Agriculture, Jakarta (Biro Perencanaan 1988).

Agricultural Mechanisation Policies

One of the reasons farmers raise cows and buffaloes is to use them for land preparation. However, land preparation has been changing from the use of animal labour to mechanical power (tractors). The agricultural mechanisation is

Table 2. Changes in rental and real wage in the major rice-producing areas of Java, 1970–88.

Description	Wet season[a]		Average[b]	Percentage of change	
	1970	1980	1988	1970–80	1970–88
Manual labour (kg of gabah/ha)	0.80	1.05	0.63	31.0	-21.3
Women labour for weeding (kg of gabah/ha)	0.50	0.63	0.44	26.0	-12.0
Animal rental rate (kg of gabah/ha)	2.40	3.80	2.53	58.0	5.4
Tractor rental rate (kg of gabah/ha)	300.00	315.00	243.20	5.0	-18.9

[a] Kasryno (1984).
[b] Panel Petani Nasional, CAER, Bogor.

showing rapid development in some areas, for the following reasons:

(1) introductions of modern rice technologies in irrigated land induces high cropping intensity which requires fast land preparation;
(2) development of irrigation systems, through extension, expansion and rehabilitation, enables adoption of the modern wetland rice technologies; and
(3) the shortage of human and animal labour due to the opening of job opportunities outside the agricultural sector, and the increasing scarcity of pasture land.

In addition to these factors there are some social factors which induced the rapid development of agricultural mechanisation:

(1) the younger generation tends to avoid heavy work or land preparation using animals;
(2) availability of credit facilities for tractor purchasing, after sales services and extension; and
(3) demonstration effects (to some extent, although the economic reasons are the most important factors).

The main reason for farmers using mechanical power for land preparation is labour scarcity, which pushes up the wages and animal rental rates. The labour scarcities reflected with differential changes of the real prices during 1970–80 and 1970–88 in Java are shown in Table 2. The animal labour rental rate increased more than the human labour wage and tractor rental rates. The draught power rental rate in West Java, Central Java and Java as a whole increased at a higher rate than human labour wage. In general there is a tendency to substitute mechanical power for animal and human labour in land preparation.

As has been mentioned, the emergence of the later mechanisation policies is partly due to the scarcity and slowness of draught animal development. This has resulted in a rapid increase in agricultural mechanisation both in Java and elsewhere in Indonesia. In West Java, the low number of draught animals and landless labourers has resulted in a much higher increase in tractors than in other major rice-producing regions.

Draught Power Supply and Cultivated Land

The latest evidence shows a quite promising increase in the draught livestock population (Table 3), which is higher than expected. This may reflect the seriousness of the government efforts to overcome the animal labour scarcity problems, and to simultaneously achieve other benefits from cow and buffalo rearing.

The actual animal numbers of cows and buffaloes in 1986 reached 6733 thousand head (136%) with growth rate higher than the targeted figure, at 6.14% compared to 1.2% in the first 3 years of the Fourth Five-Year Development Program. With an estimated 6.7 million head of effective animal labour, we should be able to prepare 16.8 million ha of agricultural land. At the same time the total area of agricultural land which must be prepared is 17.6 million ha. This indicates that there is still an animal labour shortage. The animal labour shortage is estimated to be even higher than the above figure, due to the inappropriate distribution of the draught animals, low mobility, and low effective utilisation rate.

Manure production from the draught animals should follow the population trend. It is quite interesting to reveal that the amount of manure produced by the animals reached 77.2% of the total manure production in 1986. The total manure

Table 3. Animal population, estimated power supply and cultivated land, 1984–86.

	1984	1985	1986	Trend (%/year)
		'000 head		
Population target[a]	9284	9390	9497	1.1
Actual population[b]	11488	12356	12929	5.1
DA population[c]	5955	6428	6733	6.1
Cultivable land	14888	16070	16833	6.1
Total harvested area	17192	16626	17640	1.3

Source: Direktorat Bina Program 1988; Biro Perencanaan 1988.
[a] Population target in Pelita V is 13.7 million head by 1989.
[b] Cattle and buffalo.
[c] DA population estimated as 52% of total population.

Table 4. Targets for meat consumption and production in Pelita V, 1989–93.

	1989	1993	Trend (%/year)
	kg/year		
Meat consumption per capita			
- cattle and buffalo meat	1.87	1.88	0.13
- other meats	3.47	4.07	3.99
	1000 t		
Total domestic consumption			
- cattle and buffalo meat	332	363	2.23
- other meats	618	783	5.92
Total production			
- cattle and buffalo meat	347	419	4.71
- other meats	689	928	7.42

Source: Ditjen Peternakan 1987.

production is only sufficient to meet 16.07% of manure requirement of farms.

By the end of the Fifth Five-Year Development Program (1993) the draught animal population is projected to reach 4.75 million head, sufficient to prepare 24.4 million ha of land. The manure production should reach 98 million t, or about 69.5% of the total manure production. The manure production should be sufficient to meet the requirement of 5.2 million ha of agricultural land.

Meat Production and Consumption

National meat production has always been dominated by the ruminant livestock, especially cows. The actual beef production during the 1984–86 period reached 28.5% of the total meat production. For future development policies, the role of broilers and other animals is becoming increasingly important. The present policy seemed to be quite successful during the Fourth Five-Year Development Program.

In the present Fifth Five-Year Development Program, the role of animals other than cows and buffaloes in meat production is expected to be even more important. This is shown in Table 4, where the target meat consumption per capita for broilers, other animals and other poultry is set lower than for cows and buffaloes. The policies to substitute draught animal meat consumption with other sources will be beneficial for future draught animal development. Similar information on the targeted production and consumption of various animals during the Fifth Five-Year Development Program is presented in Table 4.

Draught Livestock Intensification Policy

To promote draught livestock development the government has decided to launch the Draught Animal Intensification Program (INTEK) through the Minister of Agriculture Decree No. 9, 1984.

The target and achievements of the INTEK program since its inception (1985–86) until 1987–88 are presented in Table 5. The achievements through the credit INTEK Program were low compared with the self-financed INTEK program or INTEK Swadana (1.5% vs 130%). The rate decreased over time through the self-financed INTEK, whereas the rate through the Credit INTEK increased from 0.57% in 1985–86 to 4.2% in 1987–88. The INTEK actual in 1987–88 was only 45% of the targeted

Table 5. Targets and achievements for INTEK program, 1985-86, 1987-88.

	Credit animals		Other activities[a]	
	Target	Actual	Target	Actual
	head		*head*	
1985-86	8400	48	60600	123624
1986-87	9500	103	22000	31680
1987-88	4550	192	51070	18385

Source: Direktorat Bina Program 1988.
[a] Other Activities includes extension contacts with livestock farmers and marketing services.
N.B. The major distribution of draught animals falls within the transmigration program. Approximately 58000 head are distributed annually to these areas, accounting for 90% of total distribution.

Table 6. Interregional trade matrix of large ruminants, 1987 ('000s head).

	Importing regions					
Exporting region	Sumatera	Jakarta	West Java	Kalimantan	East Indonesia	Total
Central Java	-	68.5	99.3	-	-	167.8 (34.2)
East Java	4.3	126.5	34.8	12.0	-	177.3 (36.2)
Bali	-	22.0	-	-	-	22.0 (4.5)
West Nusa Tenggara	0.5	16.5	2.5	-	-	19.5 (4.0)
East Nusa Tenggara	-	40.5	-	-	4.0	44.5 (9.1)
Sulawesi	0.5	28.7	-	28.3	1.4	59.0 (12.1)

Source: Directorate of General Livestock Service, Jakarta.

270 810 farm households distributed in 14 provinces.

In the beginning of the Fifth Five-Year Development Program (1989) the INTEK target was 4750 packages, which is increased by 4.5% annually. The credit INTEK acceleration is placed second highest after the credit for pork. By the end of the Fifth Five-Year Development Program (1993), the credit INTEK is projected to reach 5700 packages, that is 1.9% of the total packages in the livestock subsector. If we look at the Credit INTEK Program achievements during the Fourth Development Program, the actuals during the Fifth Five-Year Development Program would not change very much, unless the government is able to make significant improvement in field implementation.

Livestock Trade Policies

The draught animal (cow) interisland trade is regulated by the Director General of Livestock, which further translates into local government regulations. This interisland trade quota will partly determine the draught animal development in producing centres. This interisland trade allocation is largely intended to meet the meat demand for Jakarta (61.8%) and West Java (27.9%). The meat demand in the two main consuming regions is mainly supplied from East Java (36.2%) and Central Java (34.2%). The major surplus regions outside Java are Sulawesi (12.1%) and East Nusa Tenggara (9.1%) (see Table 6). No export of large livestock is permitted.

Conclusions

The livestock subsector has received a relatively higher budgetary allocation than food crops and the estate subsectors. The main problem is to create an appropriate development environment, using the budget effectively and increasing the contributions of the livestock subsector to GDP, to achieve better results.

The main factor which affects agricultural mechanisation in Indonesia is the increasing scarcity of human labour and animal power at peak periods of land preparation. This is due to the adoption of modern technologies in food production, including rapid developments in synchronised irrigation. Nevertheless, since agricultural mechanisation is selective in application there remains great potential for draught animal development, especially in areas where tractors cannot operate. A further option is to increase DAP research in high-intensity land-use areas, to determine whether more draught animals can be reared by means which are profitable to the farmer and provide draught work at a rental rate that is competitive with tractors.

In the Fourth Five-Year Development Plan (1984–88) the increase in draught animal population exceeded the target set. However, increase in animal numbers has not been sufficient to match the increase in cropping area. In the Fifth Five-Year Development Plan (1989–93), distribution of draught animals to the transmigration areas is the main policy priority. Continuous monitoring and evaluation of these animals' utilisation in the new settlement areas is essential. The other problem of livestock development in the future is meeting the domestic and export demands for meat.

In general, the first 3 years (1985–86/1987–88) of the Draught Animal Intensification Program (INTEK) have been quite successful. Results from the associated Credit INTEK have been less encouraging. It is important to conduct an evaluation of the Credit INTEK program to determine why farmers did not use the program as expected.

There is growing argument that the quota system for some producing regions such as East Nusa Tenggara should be reconsidered to enhance draught livestock development in other regions. Cows are not widely used for labour source in East Nusa Tenggara, whereas in other regions it is an important source of labour for land preparation.

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Technical Efficiency and the Significance of Draught Animal Power for Rice Production in Indonesian Villages

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Abstract

Eleven Indonesian villages in which a significant number of farmers employ draught animal power in their cultivation processes were analysed using econometric techniques, to determine whether they were (a) technically efficient in their rice production processes, and (b) whether draught animal power was an important significant input in the production of rice.

Introduction

In this paper findings are reported from an investigation into whether rice farmers who use draught animals from a range of areas in Indonesia are technically efficient in their production of rice.† The major species of draught animals in Indonesia are cattle and buffaloes, and it is generally acknowledged that as well as providing draught power these animals serve many important purposes on the farm, such as providing a relatively liquid form of capital, acting as a store of wealth and the production of meat. Draught animal power (DAP) was one of the inputs to rice production included in the analysis.

The central question of the study was the hypothesis that 'within their physical and economic environments and the existing technologies of crop production and animal husbandry, rice farmers in the areas studied are technically efficient in the use of their resources, including draught animals.' The hypothesis was tested by estimating production functions from cross-sectional data derived from farm surveys in West Java, East Java and Lombok Island of Indonesia and was accepted as being true. Such knowledge about the technical efficiency of rice producers in Indonesia is valuable because it can indicate to policymakers whether future increases in production will be achievable through greater emphasis being placed on: (a) research to shift the production function upwards; or (b) from increasing extension to inform farmers how to increase their efficiency with the current technology.

Economic efficiency is composed of two components, namely, technical efficiency and allocative efficiency. Allocative efficiency refers to the extent to which a farmer combines inputs to achieve the greatest financial gain. Technical efficiency is concerned with the efficiency of the transformation of inputs to physical output. That is, for efficient production farm output should lie on the envelope curve, or production function, which traces out the maximum quantities of output from varying quantities of inputs under a given technology. When technical efficiency is defined in terms of maximum output from a given bundle of measured inputs, it means that only those farmers who are technically efficient will operate on the production function. Farms whose input-output peformance falls below that of farms on the production function are classed as being technically inefficient.

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† The findings discussed in this paper come out of a larger study 'Technical Efficiency of Rice Production in Selected Villages of Indonesia' N.M. Esparon 1989, unpublished master's thesis, The University of Melbourne.

Table 1. Village profiles.

Source	*Desa*	*Kabupaten*	*Kecamatan*	DAP Input	DAP Marginal Product (hours/ha/crop)	
No 9 W.J. PATANAS	Pagelaran	Pagelaran	Cianjur	46	24	(9.4)
No 11 W.J. PATANAS	Nagrak	Banjaran	Bandung	109	11	(4)
No 14 W.J. PATANAS	Pamoyanan	Ciawi	Tasikmalaya	13	ns	
No 15 W.J. PATANAS	Cipanas	Tanjungkerta	Sumedang	96	ns	
No 7 E.J. PATANAS	Malingmati	Tambakrejo	Bojonegoro	132	-4	(2)
No 11 E.J. PATANAS	Prayungan	Sumberrejo	Bojonegoro	53	ns	
No 12 E.J. PATANAS	Sumberkalong	Kalisat	Jember	90	ns	
No 24 E.J. PATANAS	Sumberrejo	Gondang	Nganjuk	81	2	(1)
W.J. DAP Survey	Padamulya	Pagaden	Subang	152	9.7	(7)
W.J. DAP Survey	Tanjungwangi	Subang	Subang	118	15	(9)
LOMBOK Survey	Jontlak	Central Lombok	Lombok	293	ns	

Standard errors in parentheses.
Source: Esparon (1989).

The difficulty in testing for technical efficiency is to estimate production functions which accord with the above theoretical definition. Regression methods which use ordinary least squares (OLS) with the assumption of a normally distributed disturbance do not usually provide such functions. Recent advances in the theory and practice of estimating stochastic 'frontier functions' have brought empirical estimates of production functions much closer to their theoretical definition of envelope curves or frontiers. In this study of technical efficiency the reasoning of Farrell (1957) is followed. According to Farrell (1957) technical inefficiency arises when more than the least bundle of inputs are used to produce one unit of output. Estimation of the frontier production function in this study is based on the model proposed by Aigner et al. (1977).

Important determinants of rice production in Indonesia are land area, the form of power (e.g. labour power, tractor power or DAP), fertilisers and seasonal effects (Soekartawi and MacAulay 1982; Nehen 1983; Kasryno 1985; Siregar 1987). To date, studies by Soekartawi and MacAulay (1982), Nehen (1983), and Kasryno (1985) have considered DAP as a determinant of rice production in Indonesia. These studies have all shown that DAP is a significant variable, although in one case cited by Kasryno (1985) DAP was not significant. However, little attention has been given to the question of technical efficiency in Indonesian rice production, as indicated by the paucity of studies in the area. The only study to consider technical efficiency in Indonesia in a framework similar to that used in this study is that of Siregar (1987), though DAP was not included in this estimated function for rice production.

The Data

This study used cross-sectional survey data of farms from eleven *desa* (villages) of Indonesia. Eight *desa* were surveyed by the West and East Java National Panel of Farmers Study (*Penelitian Panel Petani Nasional* or PATANAS) surveys, information from two *desa* was collected by the DAP Project survey, and information from one *desa* in Lombok Island, Indonesia, was gathered by Sarwono referred to in this paper as the LOMBOK Survey.* The eleven *desa* selected for analysis are given in Table 1.

The measurable inputs to the production of rice were:

1. Area, measured in hectares;
2. Preharvest labour, measured in hours or days. This included all classes of labour without differentiating by sex or age used in land preparation, planting, weeding and fertilising. Harvesting labour was included for PATANAS West Java;

* The PATANAS data were provided by the Center for Agro-Economic Research, Bogor, Indonesia. I would like to thank Dr F. Kasryno and all his staff (especially Mr Stanley Wood and Mr Sjaiful Bahri (Asep)) for their considerable help.
DAP Project was sponsored by ACIAR to study the multidisciplinary roles of DAP in Indonesia. Two villages in Subang were selected and daily information about their farm activities were closely monitored.
The LOMBOK Survey was undertaken by Mr Djoko Sarwono in 1987 in *desa* Jontlak.

3. Urea measured in kilograms;
4. TSP (triple superphosphate) measured in kilograms;
5. Fertilisers applied which was recorded in Rupiah;
6. Pesticides applied which was recorded in Rupiah. The pesticides were mostly Hopsin, Furadan and Diazinon.
7. DAP:

   West and East Java PATANAS — animal power was measured in hours. It was not possible to distinguish between the sources of animal power, that is, whether buffaloes or cattle were used. Buffaloes are by far the most likely source of animal power in West Java, whilst cattle are more common than buffaloes in the four *desa* analysed in East Java.

   DAP Survey — animal power was measured in days. Buffaloes and cattle were used either in pairs or singles. In *desa* Padamulya and *desa* Tanjungwangi 55% and 73% respectively of the sampled farmers used animal power.

   LOMBOK Survey — animal power was measured in hours. There were two methods of using draught animal power. The first type used pairs of cattle to pull draught implements and the other method used a group of buffaloes to trample over the *sawah* plots.

Methodology

The stochastic frontier as proposed by Aigner et al. (1977) can be expressed as: $\ln Y = f(\ln X) + \epsilon_i$ where the error term, ϵ_i, in these models is composed of two components, ν and μ. The symmetric component ν accounts for purely random variation of the frontier across farms due to effects of measurement error, other statistical 'noise,' and/or random shocks outside the control of the farm. Thus the frontier itself can vary randomly across farms, or over time for the same farm. The other one-sided component μ is truncated at zero and captures the effects of technical inefficiency relative to the stochastic frontier. That is, μ_i pushes the farm below its stochastic production frontier. This nonpositive disturbance μ_i means that each farm's output can only lie on or below the frontier. Any such deviation is under the farmer's control, and this is attributable to technical inefficiency.

According to Aigner et al. (1977), the variances of ν_i and μ_i can be estimated, to give evidence of their relative size (where $\lambda = \sigma_\mu / \sigma_\nu$ given that $\sigma^2 = \sigma^2_\mu + \sigma^2_\nu$). From the value of λ it can be decided whether the disturbances are due to the symmetric or nonpositive errors. For example, when $\lambda^2 - 0$ it implies that either $\sigma^2_\nu \rightarrow \infty$ and/or $\sigma^2\mu \rightarrow 0$. In this case the symmetric error dominates in determining of value of ϵ_i. When this occurs the conclusion is that farmers are technically efficient in their use of this particular bundle of inputs, and any differences in their level of production are due solely to the symmetric random errors. When $\lambda \rightarrow \infty$ the nonpositive errors become the dominant source of the disturbance and the density function of ϵ then takes the form of a negative half-normal (Aigner et al. 1977, p. 26), and the conclusion is that farmers are technically inefficient. In this study the stochastic maximum likelihood estimates (MLE) production frontier model of Aigner et al. (1977) was estimated using LIMDEP, the statistical package of Greene (1986). The parameters estimated in the LIMDEP frontier regression model are β, λ and σ^2.

A linear model was used for estimating the production functions for rice. This model was chosen partly because zero levels of inputs for some farms precluded the use of the Cobb-Douglas model. Further, a model without an intercept was preferred to a model with an intercept because no inputs in agriculture results in no production.

Empirical Results

The OLS rice production functions for all eleven *desa* are summarised in Tables 2 and 3.

Lombok Survey In *desa* Jontlak rice farmers use two different techniques of land preparation. One technique uses buffaloes for trampling, and the other technique uses buffaloes for pulling ploughs. Two linear production functions were estimated (Table 4): with case I the two different land preparation techniques were regressed as independent variables; and with case II a dummy variable was used to distinguish between the two different techniques of land preparation. For case I the only positive significant variable affecting rice production between these *sawah* plots was land area. Results from case II showed that the dummy variable for the different techniques of land preparation was not significant. This implies that there were no significant yield differences achieved between the trampling or ploughing techniques of land preparation.

Production functions for pooled data Three linear OLS production functions (referred to as cases I, II, III) were applied to the pooled information of *desa* 9, 11 and 14 of West Java

Table 2. Levels of significance of variable inputs.

	Area (ha)	Lab	DAP	Urea	TSP	Pest	Fert	Season
Desa 9 West Java	ns	ns	**+	**+	ns	–	–	–
Desa 11 West Java	**+	ns	**+	**+	ns	–	–	–
Desa 14 West Java	**+	ns	ns	ns	ns	–	–	–
Desa 15 West Java	**+	**+	ns	**+	**+	–	–	–
Desa 7 East Java	**+	**+	**–	**+	**–	–	–	–
Desa 11 East Java	**+	ns	ns	ns	ns	–	–	ns
Desa 12 East Java	**+	ns	ns	**+	ns	–	–	ns
Desa 24 East Java	*+	ns	*+	**+	ns	–	–	ns
Desa Padamulya	*+	**+	ns	*–	**+	ns	–	ns
Desa Tanjungwangi	ns	ns	*+	**+	ns	ns	–	–
Desa Jontlak	**+	ns	ns	–	–	ns	ns	–
No. of time sign.	9/11	3/11	5/11	8/10	3/10	0/3	0/1	0/4
Pooled information 9,11,14 West Java	**	ns	**	**	ns	–	–	–

**+ significant and positive at the 5% level.
*+ significant and positive at the 10% level.
**– significant and negative at the 5% level.
*– significant and negative at the 10% level.

Table 3. Marginal products for all *Desa*.

	Area (ha)	Lab	DAP	Urea	TSP	Pest	Fert	Season
Desa 9 West Java	ns	ns	24	10	ns	n	n	n
standard error			9.4	4.4				
Desa 11 West Java	3995	ns	11	6	#	n	n	n
standard error	1281		4	3				
Desa 14 West Java	7315	ns	ns	ns	ns	n	n	n
standard error	1416							
Desa 15 West Java	3743	0.4	ns	2	3	n	n	n
standard error	836	0.1		0.7	1			
Desa 7 East Java	1236	0.8	–4	7	–4	n	n	n
standard error	334	0.3	2	1	2			
Desa 11 East Java	4721	ns	ns	ns	ns	n	n	ns
standard error	801							
Desa 12 East Java	2730	ns	ns	3	n	n	n	ns
standard error	401			1				
Desa 24 East Java	1430	##	2	5	ns	n	n	ns
standard error	402		1	1				
Desa Padamulya	1678	11	9.7	–3	6	–0.01	n	–201
standard error	886	5	7	1	2	0.01		241
Desa Tanjungwangi	ns	ns	15	6	ns	ns	n	n
standard error			9	2				
Desa Jontlak	7041	ns	ns	n	n	ns	ns	n
standard error	1501							
Pooled information	2764	ns	12	8	4	n	n	n
9,11,14 West Java	856		3	3	3			
standard error								

ns Not significant variables.
n Variable not used in the input matrix.
\# TSP was dropped because it was highly correlated with urea.
\## Labour was dropped because it was highly correlated with area.

Table 4. OLS linear production functions of sampled *sawah* plots in *Desa* Jontlak, Lombok 1987–88.

	Case I	Case II
Dummy for land preparation	-	-181.17
D1 = 1 for ploughing		(186.8)
Area (ha)	5989.61**	7200.5**
	(1509)	(1625)
Preharvest labour (hours)	0.17	-2.24
	(2.98)	(2.81)
Ploughing animal (hours)	-7.7	-
	(8.2)	
Trampling animal (hours)	0.99	-
	(4.5)	
Fertilisers (Rp)	-0.046	-0.05*
	(0.029)	(0.026)
Pesticides (Rp)	0.03	0.069
	(0.11)	(0.124)
adj R^2	0.83	0.72
F statistic	15.03**	14.18**
Durbin-Watson Test	1.86	1.65
Breusch-Pagan 'Q'	9.48	8.34
Critical value $\chi^2_{0.05}(p-1)$	12.59	9.49
Sample size	21	21

Standard errors in parentheses.
** Significant at the 5% level.
* Significant at the 10% level.

The quantity Q = ESS/2 is, under the null hypothesis, asymptotically distributed as χ^2 (p-1). Thus if Q > $\chi^2_{0.05}$ (p-1) one would reject the null hypothesis of homoscedasticity at the 5% level (Breusch and Pagan 1979).

Table 5. Pooled OLS linear production functions for sample rice farmers from West Java (*Desa* 9, 11 and 14).

	Case I	Case II	Case III
Dummy for *desa* 11	-706.12**	-612.66**	-698.16**
	(220.3)	(302.6)	(249.2)
Dummy for *Desa* 14	289.62*	-0.511	178.72
	(160.6)	(177.9)	(241.0)
Dummy for DAP	-	-114.3	-
Users		(209.9)	
Area (ha)	3173.63**	5549.24**	2764.35**
	(723.8)	(633.4)	(865.0)
Total labour (hours)	0.132	0.305**	0.114
	(0.106)	(0.115)	(0.121)
DAP (hours)	10.75**	-	11.89**
	(2.14)		(2.65)
Urea (kg)	7.87**	7.96**	7.78**
	(2.09)	(2.41)	(2.58)
TSP (kg)	2.53	-2.15	3.81
	(2.67)	(3.15)	(3.37)
adj R^2	0.97	0.96	0.97
F-Test	413.53**	310.27**	305.97**
Durbin-Watson Test	2.49	2.17	2.49
Sample size	85	85	62

** Significant at the 5% level.
* Significant at the 10% level.
Standard errors in parentheses.

(Table 5). For case I animal services was used as one of the regressors, whilst the regression equation of case II contained a dummy variable for farmers that used animal power. Case III was a regression for production only by those farmers that used DAP. From case I significant variables to rice production were the coefficients for land area, animal services and urea application. From case II it was shown that users of animals were not significantly different in their technical efficiency of the production of rice compared to those farmers that did not use animal power to cultivate their land. From case III the marginal product (MP) of extra animal power at current levels of usage was obtained.

MLE frontier production functions Using the LIMDEP software package of Greene (1986), stochastic frontier functions were estimated, using MLE, for all eleven *desa* separately, and also for the pooled information of *desa* 9, 11 and 14 of West Java. Results from the stochastic frontiers indicated that all farmers studied in each of the eleven *desa* were technically efficient in their rice production, i.e. farmers were technically efficient when compared with each other in the same *desa*.

Discussion

The main point to note is the extent to which the significance and marginal productivity of inputs to rice production varied, *desa* by *desa*. There are few widely applicable general conclusions, which means that detailed case by case approaches to specific questions about rice production efficiency in specific areas and farms is required as an adjunct to approaches such as this one.

The significance of variables and their marginal productivity are summarised in Tables 2 and 3 respectively. Land area was a significant, positive variable for rice production in nine of the eleven *desa*. For eight out of the eleven *desa* some form of fertiliser was shown to be a significant input. In some cases the other variable inputs were significant determinants of rice production, but these varied greatly among different *desa*. The results illustrate the different responses received in rice yields under the conditions of production in each *desa*. Manual labour measured in this study included labour for land preparation, and crop husbandry, and for the West Java survey this also included harvesting labour. Labour was a significant and positive contributor to rice production for only three of the eleven *desa* analysed. The presence of significant, positive MP for labour could be due to labour being limiting for certain times, or could be due to labour having an opportunity cost higher than the value of the extra production, or could be due to the impact of risk, e.g. unanticipated extra output due to favourable seasonal variation.

Land cultivation in the surveyed *desa* was done by manual labour, DAP and tractors. DAP was a significant, positive variable for rice production for four out of the eleven *desa*, and was significant and negative for rice production in one *desa*. The MP of rice for DAP for the pooled information of *desa* 9, 11 and 14 of West Java PATANAS was significant and positive at a value of 12 kg of rice for one extra hour of animal power. The most notable aspect of the MP of DAP is the difference between the results for East and West Java. In East Java the MP for DAP were either insignificant or small (-4, 2 kg of rice). From the PATANAS survey in West Java, DAP had significant MPs of 24 and 11 kg of rice in two out of the four *desa* analysed. The DAP Survey in West Java revealed significant DAP MPs of 10 and 15 kg of rice for *desa* Padamulya and *desa* Tanjungwangi, respectively. These MPs from the West Java PATANAS and DAP surveys are moderately similar. More importantly, in East Java, which has a much higher density of draught animals (including cattle) than does West Java, the MPs for DAP were much less than in West Java. The higher MP findings for the West Java areas imply that the supply of DAP is a limiting factor or constraint in the West Javanese farming systems. In East Java, which had a higher density of animals, the MPs were close to zero. This suggests the supply of DAP services was much less of a constraint on production in rice production systems in East Java.

For the pooled sample of West Java, results showed that the dummy variable for animal users was not significant. This means that rice yields did not differ significantly irrespective of the techniques of land preparation used. Empirical results from *desa* Jontlak indicated that there were no statistical differences in the rice yields obtained by ploughing or by trampling. Research by Nehen (1983) showed that for the dry season tractor cultivation achieved higher yields than did animal power, which in turn outperformed manual cultivation. For the wet season, Nehen (1983) found rice yields using animal power were higher than output achieved using tractor power, which was in turn superior to manual cultivation.

If the different land preparation techniques in practice were to be pure technical substitutes (which Nehen 1983 disputes) then the price of renting animal power would be determined by the supply of buffaloes as well as the supply of alternative sources of power. This has important significance if true, as the implication for the future of DAP in Indonesia would be that if the supply of draught animals grows relatively slowly (and does not become relatively cheaper) then their use in the longer term may (depending on relative prices) be most important in areas where mechanisation is not possible and where there are shortages of labour for land preparation.

Conclusion

The main finding from this study is that all farmers in these eleven *desa* are achieving high levels of technical efficiency. Given the techniques they are using, the rice farmers studied are technically efficient. Or, within their environment and given their level of technology, these Indonesian rice farmers are using their technology efficiently.

The finding of technical efficiency has some implications for *both* research and extension. If these farmers are as technically efficient with their current technology as is practically possible, this would mean that there will be: (a) no need to inform these farmers of ways to increase their production using the *same* technology; and (b) future gains in productivity will have to come from shifts in the production function. This would involve new technologies being introduced to the production of rice, which would imply that there is a significant need for technical research into such things as reducing the effects of limiting factors, and increasing the potential output through improved varieties. This finding does *not* deny that extension services need to be done. After all, it may be that higher technical efficiency is possible with currently known, but not used, technology. If this is so then extension effort would be needed to inform rice farmers of such findings.

Land area was the most significant determinant of rice production in Indonesia. But, given the limited availability of land for rice production, productivity changes will have to come from the nonland inputs. Other significant inputs to rice production varied across *desa*, with urea, DAP and labour featuring as significant in various *desa*. The significance of DAP varied considerably among the different *desa*. DAP was a significant, positive variable for four of the eleven *desa* analysed, and a significant negative input in one *desa*. Interestingly extra output derived from extra DAP in rice production was markedly higher in West Java than East Java which could mean that there may be demand for greater DAP use in West Java if the animals were available, depending on price of course.

Finally, the differences in the importance of various inputs to rice production in different *desa* throughout Indonesia is indicative of the sometimes subtle but always significant technical, economic and human 'uniqueness' of rice production in particular areas on particular farms. The validity of findings from general surveys to particular farms has to be assessed for each case. Thus assessments of technical and economic efficiency by well-trained people at the farm level will remain an important and valuable task.

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Indonesian Smallholder Cattle Development Project: Description of the Credit Component

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Abstract

A project to assist smallholders in the outer islands of Indonesia to increase food crop production through the provision of draught animals began in 1981, supported by the International Fund for Agricultural Development. The project is intended to improve the long-term domestic supply of livestock to the Indonesian Islands (other than Java), through a credit program to strengthen the Directorate General of Livestock Services (DGLS) and increase forage production and develop a forage seed production credit component to be implemented through smallholders in the poorer areas of the Eastern Islands.

The concept for the project to assist transmigrant livestock and food crop development in Indonesia was the outcome of a World Bank Cooperative Program Livestock Sector Survey in 1977. The project (Phase I) proposed the procurement of 45 000 Bali cattle in East Java (Madura cattle) and South Sulawesi, and NTT for distribution in Sumatera. The major objectives are to: (a) increase overall productivity and employment and to raise the incomes of the project farmers; (b) increase food crop production by increasing the area under cultivation and yields; (c) provide draught animal support to (a) and (b) above and introduce credit for the draught animal distribution program, and the forage seed production component; and (d) provide a package of technical services, forage seed and forage programs to farmers, including credit collection. The project has been particularly successful in implementation in both physical and financial aspects, due to the administrative structure and management systems instituted at project start-up.

Introduction

THE Transmigration Program in Indonesia, while providing a house, seeds, food support, etc. to transmigrants, was not making credit available until the implementation of this project. The outer islands, traditionally less fertile than Java, and the transmigrants being mainly young families, lacked the resources to develop the land, especially land cultivation.

This project was designed primarily to give the transmigrant access to credit to purchase a draught animal, plough and to receive the necessary technical support (e.g. forage development, animal health, etc.). An important long-term objective was to make the transmigrant aware of credit use and responsibility. Phase I of the project began in 1981-82 and was completed in 1986-87. It was funded by the International Fund for Agricultural Development (IFAD) (US$26 million) with counterpart funds from the Government of Indonesia — US$14 million. Phase II began in 1986-87 with funding from the World Bank (US$32 million), IFAD (US$12 million) and the Government of Indonesia (US$22 million).

The Phase II Smallholder Cattle Development Project Credit Scheme is an example of a project designed to provide credit. Some results of the scheme after 7 years of operation are presented in this paper.

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Objectives

Cattle play an important role in the development of agricultural production in Indonesia, traditionally as the primary source of draught power, but are increasingly important as a capital reserve and a source of cash income. Development in the Outer Islands, especially in transmigration areas, has been constrained by undercropping due to inadequate farm labour or lack of draught power. The project was designed to increase agricultural production by overcoming the constraints of draught animal power.

The major components of the project as it was designed were:

(a) Cattle procurement and distribution in Phase I provided for procurement of 45 000 head phased over 6 years from overstocked areas in the Eastern Islands and distributed mainly to transmigration areas in five provinces in Sumatera; in Phase II 84 500 head will be distributed over 6 years.

(b) Infrastructure for cattle transfer: quality control centres, quarantine stations and holding yards in the procurement areas; improved port facilities; and of receiving stations at the distribution points.

(c) Forage improvement: improved forage production on farms, introduction of adapted pasture legumes, seed production.

(d) Institutional development: creation of project management office in DGLS and development of services at the district and village level.

(e) Program support: consulting services, monitoring and evaluation and cattle disease research.

Organisation

The success of the project, especially credit collection (averaging 81% in year 6) is due mainly to the manner in which the management structure was designed, so that authority was delegated with the corresponding accountability.

The project is managed at the national level through the Project Management Office (PMO) whose prime functions are to: ensure project policy is implemented; ensure that budgets are obtained from government and reimbursements from loan funds are on schedule; contract and implement major contracts; and monitor the project continuously for physical and financial performance and measure impact.

At the provincial level the project is managed by a Project Management Unit (PMU) which provides support to field staff in: coordination of overall activities within the project locations; coordination with provincial authorities involved in transmigration; local financial matters; and technical guidance to field staff.

At the location level the field staff (Satgas) are responsible for: distributing the original animals and necessary documentation (e.g. Credit Notes); collecting credits by redistributing animals and selling surplus males and culls; ensuring the farmers establish forage and utilise it; animal health, both routine and emergency; monthly reports on animal performance (e.g. births, deaths, credit repayments); and coordination at field level between all entities concerned (e.g. transmigration, Bank Rakyat Indonesia, etc.).

The Credit Scheme

Draught Animal Credit Component

The Credit Concept

The concept of credit in this project varied from existing Government of Indonesia Credit Programs, in that the package: provided one draught animal per farmer plus a noncredit technical services package consisting of forage development, animal health, and field staff being on site; monitored the value of the animals returned as payment and if the local market value was greater than the original CIF value plus interest the farmer was refunded the cash value; required the animals collected as credit to be redistributed within the same village until all farmers had received one animal; ensured that credit flow was clearly defined through a series of agreements: loan agreement between the COI and IFAD; financing agreement between the Ministry of Finance and Bank Rakyat Indonesia (BRI); subfinancing agreement between BRI and the DGLS; credit agreement between the BRI and recipient farmer.

Credit collection was the responsibility of the project itself with the field staff actually collecting in-kind and redistributing and/or selling the surplus/cull animals.

A key factor in the implementation of this credit was ensuring prior to implementation all levels of Project management and recipients fully understood the procedures for obtaining the credit, the system of processing the credit and the repayment of the credit. It was made very clear at all levels where, why and how much responsibility lay in the credit process, especially collection.

To implement the concept extensive training was carried out. Satgas and farmers are trained extensively prior to cattle distribution in the credit systems. Emphasis was placed on the public meetings between key farmers, farmers and Satgas to explain and demonstrate with diagrams the actual credit documents and how the process operates. If an area was detected as developing some weakness a special 'task force' from PMO Jakarta visited the area.

Guidelines and Regulations

As mentioned previously the project developed a series of project guidelines and regulations to ensure that the credit would be available to farmers and that they would repay that credit. It would be useful if we look briefly at some of the details of this.

It has always been project policy that close coordination be maintained with all government entities directly and indirectly associated. This has been a major reason for the success of the project to date. Policy has also dictated delegating authority and concurrent responsibility.

The subfinancing document provided for a number of processes among which were: the actual site selection in Transmigration areas was undertaken by a task force whose members consisted of the Projects Provincial Management Unit (PMU), the Provincial Livestock Inspector, the Provincial Governor's Office, the Regional Transmigration Office, Bank Rakyat Indonesia (BRI) and the Kabupaten Government (District). When the 'task force' had completed its selection of sites this was confirmed by a decree issued by the Provincial Livestock Inspector.

The task force operated under PMO guidelines, the principal ones being that: the site must be accessible; the site must have been settled at least one year; no similar scheme had been implemented in that location previously; the site should have soil type suitable for cattle (e.g. swamp areas were excluded); the location should have about 1500 families who have no cattle, with 500 of them being given animals and the next 1000 obtaining animals from the repayment cattle.

Information to Participants

This was provided by the task force in close cooperation with the next lower levels of government: the Kecamatan (District level) — the Kepala Desa (Village Head) — Kelompok Tani (Farmer Groups). Those farmers interested in obtaining credit were required to register with the projects and required to: complete the project application form assisted by the task force (in practice field level Satgas staff), and provide a letter from the Village Chief that the applicant was a permanent resident of the village.

Farmer Selection

This was undertaken by the task force with participation from the Subdistrict Government, Village Chief and Local BRI Office (if one was available).

Selection Criteria

The criteria were based on information supplied by the project and used as a guideline by the task force. The farmer, in order to qualify, was required to meet the following criteria: be a transmigrant or local farmer (project guidelines suggested 10% of recipients be local farmers); be a permanent resident of, and of good standing in, the community; not in possession of any draught animals; be in possession of about 2 ha of land (minimum allocation under transmigration guidelines); and be able to provide adequate fodder.

The farmer who met the above was then required to sign a formal agreement with the project which stipulated that the recipient: agrees to technical guidance (e.g. forage development schemes provided by the project); agrees to attend training sessions which cover the project concept, the credit system, recipient obligations, and technical aspects of animal management and utilisation for draught power; agrees to become a member of a farmers group; agrees to join an existing or planned village cooperative (KUD); agrees to sign a Credit Agreement with BRI.

The farmers who complied with the above and signed a formal agreement were then issued a certificate of participation.

The Credit Package

This consists of one female draught animal to every farmer and one female and one male to every tenth farmer who is normally the 'key farmer' or head of the farmer groups.

The repayment of the credit was based on the recipient of one animal repaying two animals within 5 years — one before the end of the third year and the last before the end of the fifth year. The bull recipients are required to pay back three animals, one at the end of the third year and the other two at the end of the fifth and sixth years, respectively. The age of all pay-back animals is about 18 months.

The Credit Risk

This is borne by either the farmer or the Government of Indonesia depending on cause and areas of responsibility.

The project (GOI) obligations under the credit agreement between the farmer and the BRI were: Sterile animals were to be replaced at no cost by the project. The criteria were if the cow showed no signs of pregnancy 6 months after distribution, and was mated on four subsequent occasions and did not become pregnant she was replaced. A bull was declared sterile after a semen test.

The credit was then cancelled by the BRI, a replacement animal provided and a new credit issued. The farmer could opt not to accept a new animal and drop out of the scheme.

The obligations of the farmer are clearly spelled out in the credit agreement, and the loan falls due and payable if the animal dies of neglect by the farmer or the animal is lost through negligence on the part of the farmer.

Impact of Animal Performance on Credit Collection

The project has concentrated almost exclusively on Bali cattle (97%). During implementation many valuable lessons have been learned affecting individual animal performance, beginning at the procurement farm, transporting, distribution and subsequent on-farm management by the transmigrant. These are too numerous and varied to discuss in detail, however a few major factors will be discussed.

The first is calving performance in the first year of distribution. At appraisal 60% calving rate was projected, but in practice the project achieved only 5% for a number of technical reasons that accumulate to stress the Bali cattle. This virtually added 1 year to the credit term. No Bali cattle movement of this size had ever been undertaken (92 500 head contracted to date, 82 831 distributed and 28 000 collected as credit repayment and subsequently redistributed or sold), so it was a learning process for all concerned. The performance of the Bali cattle during procurement and distribution is summarised in Table 1.

The animal performance on farm varies according to: (1) soil type low pH; (2) off-farm work; (3) draught animal importance/utilisation; (4) soil type, high soluble aluminium; (5) long dry season, (6) technical services; (7) site/location selection; (8) original standard of site preparation; (9) animal disease/internal parasites/external parasites; (10) mineral deficiency; (11) forage development/utilisation/low nutritional intake; and (12) field staff (Satgas) inputs/efficiency.

The above factors and their combinations affected animal performance between locations. An example is Riau Province where in the third year the highest calving was 92% and the lowest 12% (Table 2).

Forage Seed Production Credit Component

Potential growers were carefully screened for their expected capacity to generate forage seed of the quality required.

As part of this process their farms were inspected and the location and size of the areas of ground to be used for forage seed production determined.

Table 1. Bali cattle performance in procurement, shipping and distribution.*

Procurement				Shipping		Receiving Grounds					Farmers		
In	Reject	Accept	Load	Mort.	Unload	In	Reject	Mort.	Out	Arrive	Reject	Mort.	Replace
101439	19058	82381	82381	493	81888	81888	1037	871	79980	79880	528	932	3861
%	19.0	81.0	-	0.6	99.4		1.3	1.1	-	-	1.0	1.1	

* Fiscal year 1981-82 to 1988-89 (partial).

Table 2. Average calving (%) from project start-up (1982-83) over a 6-year period (to 1988-89).

	Year					
(1981-83)	1	2	3	4	5	6*
Calf % (avg)	5	46	52	45	31	48
High	20	80	92	75	62	63
Low	0.2	6.3	18	19	10	24

* Calf percent drops in latter years as project drops farmers after credit repayment, so remaining farmers/cows in latter year are poorest performers.

From this it was possible to make precise estimates of the amount of seed, transplant seedlings, fertiliser, herbicide and insecticide required to initiate production by each grower.

Credit to the value calculated was issued to each grower through the Bank Rakyat Indonesia (BRI).

The duration of this credit was 3 years with interest over that period being calculated at 6%/year, with 1 year grace period without interest payment. No collateral was required for the credit issued.

Repayment was in the form of forage seed at the preagreed price of seed.

At any time within the 3-year credit period the grower could repay all or a portion of his loan with the seed that he was selling through the project. This was coordinated through the Kelompok Tani (farmer groups) that were developed within the seed-growing areas.

In addition to coordinating the repayment of credit these farmer groups served as centres for the discussion of management problems. They facilitated general extension work by the Satgas and coordination between forage seed-growing activities and other farm works. A very significant role for these farm groups was in the utilisation of the income derived from the sale of forage seed. The seed that was purchased in the name of an individual would frequently, in fact, be the production of a number of small growers. This same group then had a genuine interest in these sales after they had been placed in the savings bank account (TABANAS) of the registered seller of the seed. The farm group then became the focus of discussion and decisions on how money in these bank accounts was to be spent.

On the basis of certified records of seed delivered to the PMU, the BRI would arrange for payments to be made to the growers who had supplied the seed.

This was achieved through arrangements with the Satgas and the Village Chief to visit the locations and make payments. It was part of the agreement entered into by growers coming into the project, that half of the payments for forage seed would be placed in savings accounts opened by the individual growers.

Withdrawals from these accounts were only permitted for purchases that could be justified as productive uses of the money set aside in these accounts. Much of this was utilised for the purchase of small livestock to be used as part of the overall Kelompok production system.

Credit Administration

It was realised early that the volume of credit especially for cattle could not be monitored manually, and therefore credit control was made an integral part of the Management Information System of the Project (MIS), controlled by a mainframe computer in Jakarta. The programs of the MIS were specially written for the various project requirements.

Credit Monitoring System

This system was based on individual Cow Numbers. At procurement each animal is branded and tagged with a number which indicates the Contract number and Individual Animal number. Around this is built the whole of the project Management Information System, Socioeconomic Impact Studies, and Special Studies.

Offspring automatically receive a number which relates to the Dam number. The field staff report monthly on a number of information requirements including Calvings Dam number, Calf Mortality and Adult Mortality. This information when entered into the central computer automatically allocates offspring the number the field staff will allocate.

Credit repayments are contractually due at 18 months, so in the quarter prior to the 18 months the program will indicate animals due for repayment by showing: - Province - District - Sub-district - Satgas Unit - Village - Name and address of farmer (Creditor) - Contract no. and individual dam no.

The program also indicates those whose credits have been paid and those past due on a separate printout.

Credit Recovery, Animals

Credit recovery overall has been satisfactory with areas of very high performance and some very low areas. Performance is directly related to transmigration site conditions (Table 3).

By mid 1989 (phase I and II) the project had contracted 92 500 head of Bali cattle from the Eastern Islands (the provinces NTT, NTB and South Sulawesi) and distributed 82 381 (the balance are in process), redistributed and sold (surplus) some 28 000 head.

Credit Recovery, Forage Seed

The number of credits issued and repayment rate are shown in Table 4. Credit recovery has been particularly satisfactory due mainly to a heavy input of technical services and good cooperation with the channelling bank.

Table 3. Status of cattle credit repayment.[a]

Province	No. farmers	No. credit repaid, Year 6	%
Lampung	2626	2150	82
South Sumatera	4047	3809	94
Riau	3213	2132	66
Bengkulu	2440	1863	76

[a] No farmers with final credit payment due end of 1988.

Table 4. Amounts of credit and rates of repayment.

(Province) District	No. farmers	Credit/ farmer (Rp)	Percentage who had repaid credit		
			Year 1	Year 2	Year3
(NTB)					
West Lombok	190	7 308	73	87	100
Central Lombok	173	4 147	89	100	100
East Lombok	106	4 179	33	100	100
Sumbawa	29	12 293	3	100	100
(NTT)					
Kupang	73	27 872	–	–	100
TTS	16	22 689	–	–	100
Belu	100	9 162	–	–	100
Sumlili	74	2 027	–	–	100
Total	761	18 369	43	62	100

Conclusions

The potential for draught animal credit in transmigration remains large. Only 25% of transmigrants have had the opportunity to obtain credit to date (including all projects).

The key factors in the credit program are to ensure the farmer is given an animal (e.g. Bali cattle) that is suitable for his requirements, that the credit package is one he can handle and understands, and that in the early years (at least during the life of the credit) a complete 'package' of technical services is provided. One of the most important components of the technical services package is to ensure that suitable forage varieties are provided to the farmer, that he understands their use and actually uses them. This project has expended much effort on seed production of suitable varieties adapted to local conditions. The project has produced some 150 000 kg of seed of various legumes suited to the soil types of the distribution areas.

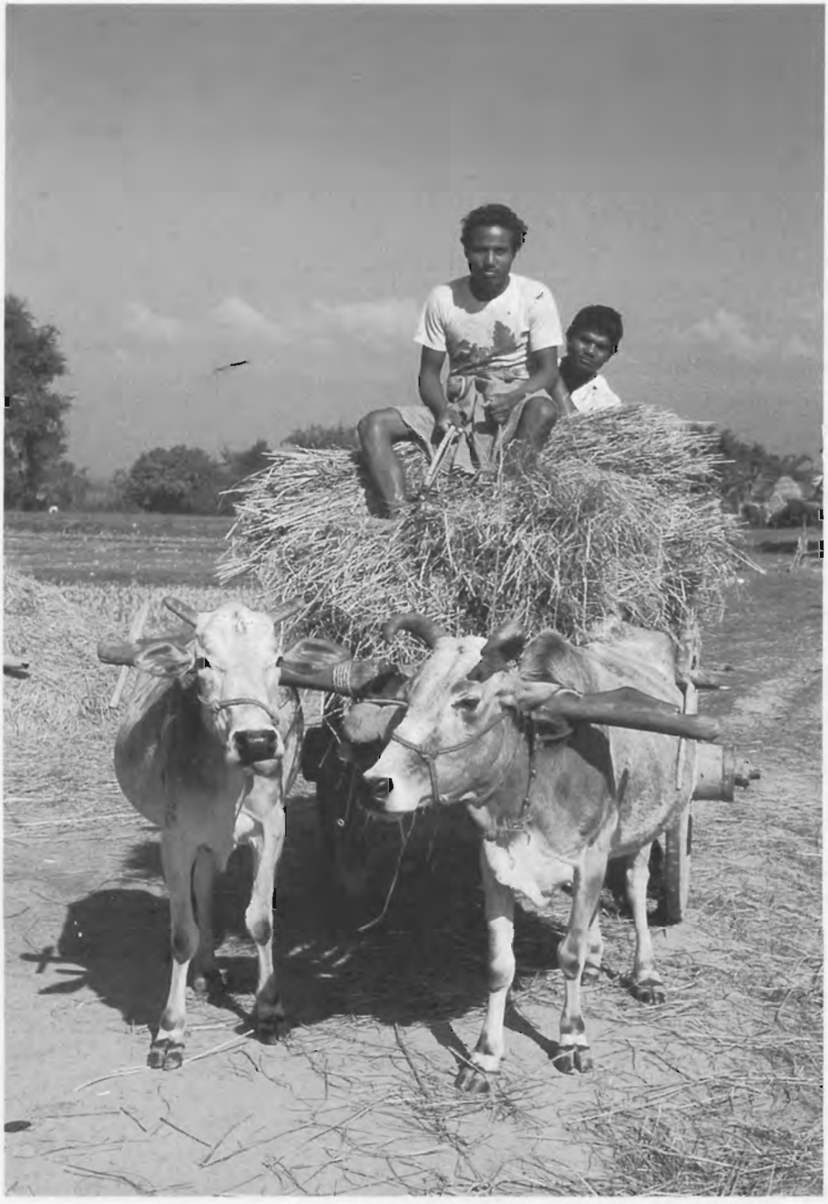
The major varieties are *Leucaena leucocephala, Desmanthus virgatus, Sesbania grandiflora,* Codariocalyx, Siratro, *Stylosanthes* spp. Forage grasses mainly Lampung setaria, *Andropogon gayanus,* Para, and King grass have been distributed as 'Pols' (cuttings). The objective is for each farmer to have the equivalent (along farm boundary roadways, etc.) of 2500 m^2 of forage.

The project at start-up concentrated on Bali cattle, which are very prolific (given average conditions), easy to train to work, works well and after an economic life has a good meat value. Most importantly they are readily accepted by the farmer.

The choice of this breed has been justified over the years and today Bali cattle make up nearly 80% of all draught animals provided to transmigrants.

There are, however, a number of matters that need to be investigated at field level to improve the on-farm performance of Bali cattle. A major one is the ploughing rates and most suitable plough types for various soil types on the outer islands. Presently this project has a cooperative program with the DAP at Ciawi, and we would like to see the program continued at least at its present level.

Field work needs to be intensified to further develop farming systems that fully integrate livestock and pay particular attention to the control of soil erosion by using a combination of forages on the contour.



Section 9
Abstracts

Abstracts

Village Visits as a Means of Motivating Farmers to Become Involved in Farm Trials

A. Thahar, Santoso, Ridwan and M. Winugroho*

Low educational levels of farmers and their consequent inability to assess the credibility of information on livestock improvement is a major constraint to the conduct of farm trials in farming systems research, and hence in the testing of technology. Marked improvement in acceptance of information amongst draught animal rearers was noted in three villages of Subang District, West Java, following a visit in July 1988 by some of the farmers to selected farmers in Central Java. It was concluded that farmers accepted ideas for trial on their farms much more readily after effective communication, i.e. in this case, of the practicality and benefits of growing improved forages and of preserving rice straw.

Such visits are seen as an essential part of the on-farm research procedure needed in village resource development. The general principles of teaching by showing and learning by doing may accelerate the process of farmer participation in farm trials, and hence success in FSR. Conversely, it can be argued that unless ideas for testing have been soundly communicated to farmers involved in a farm trial, the technology itself cannot be said to have failed.

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Period of Animal Work per Year and Liveweight Change During Working Season in Two East Java Villages

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A study was conducted from May to November 1988 in Sudimulyo village (0–100 m above sea level) and Martopuro village (300–500 m), to determine the variation in days of animal work per year and in liveweight of draught animals. The two groups of farmers studied at each village site were (A) those with <1 ha of land and (B) those with >1 ha of land.

The average period worked per year by farmers and their cattle was 43.0 and 11.8 days in Sudimulyo, and 65.8 and 38.4 days in Martopuro, for Groups A and B, respectively. Liveweight changes in draught animals during the work period (May–November) were 45.5 kg and 27.6 kg in Sudimulyo, and -24.0 kg and -11.1 kg in Martopuro for farmer groups A and B, respectively.

Statistical analysis showed that total days worked per year, and liveweight gain by draught animals, varied with agroecosystem (i.e. between villages) and was related to livestock density (>200 head/km^2 in Sudimulyo and 100–140 head/km^2 in Martopuro), and to the area of land operated by the rearer. Farmers with <1 ha of land (Group A) work their animals for longer periods (mainly on a hire basis) than those who operate >1 ha (Group B).

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Comparison of the Use of Wooden Plough and Garu/Sisir in Land Preparation from Wet Rice Cultivation in Tarus Village, Kupang, West Timor

H. Marawali, C. Liem and U. Tonga*

A study was conducted in Tarus village, Kupang District, Nusa Tenggara Timur during the 1988–89 cropping season (January-June 1989). The aim was to introduce the use of animal-drawn wooden ploughs (West Java type), to compare this with the garu/sisir (leveller/harrower), in terms of the labour requirement and also the rice production.

Attempts to introduce animal-drawn metal ploughs in West Timor started over 20 years ago and in Tarus village some farmers use this method. However, the expense of metal ploughs (Rp 70 000) and other factors appear to have deterred most farmers from adopting ploughs. Some farmers have started preparing their land with animal-drawn wooden leveller/harrows, which appear to perform better on deep, wet soils than metal ploughs (which tend to sink).

Four farmers using wooden ploughs with their own cattle and four farmers using only the garu/sisir were monitored. The average time taken for land preparation with the wooden plough was 64.1 hours/ha and with the garu/sisir, 53.3 hours/ha. The time spent by the farmers other than while working the animals for land preparation (i.e. supplying water, planting, weeding, fertilising until harvesting) was 133.4 hours/ha for wooden ploughs and 126 hours/ha for garu/sisir.

The total amount of time spent throughout the period from land preparation to harvesting, was 197.5 hours/ha for wooden ploughs and 179.3 hours/ha using the garu/sisir. The rice yields measured were 4041.5 ± 837 kg/ha for wooden ploughs and 3680.5 ± 787.4 kg/ha using the garu/sisir.

The farmers who normally use the garu/sisir in the areas with deep soil were not interested in using the wooden plough. However, farmers who normally used the metal plough in this village were very interested in using wooden ploughs, as these are much lighter and more easily made and replaced than metal ploughs. Some farmers have sold their metal ploughs in favour of using wooden ploughs in the first season of this trial introduction. The wooden garu/sisir is easier for farmers to make than the wooden plough, but the garu/sisir can only be used in very wet soil conditions and does not invert the soil.

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Comparison of Trampling by Cattle and the Use of Wooden Ploughs for Preparation for Wetland Rice in Naibonat Village, West Timor

C. Liem, A. Saleh and H. Marawali*

A study was conducted in Naibonat Village, Kupang District, Nusa Tenggara Timur in the 1988–89 cropping season on the animal trampling (merancah) and ploughing (traction) methods for rice cultivation. The aim was to evaluate the labour efficiency of the trampling method, compared to animal-drawn wooden ploughs, as a means of land preparation. The trial involved training some farmers to make wooden ploughs and to break in their animals for work. A farmer from West Java was brought to West Timor as a trainer.

Ten farmers using trampling and 10 farmers using ploughs were monitored throughout the period from cultivating to harvesting (December to June). Only the labour in land preparation

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and the rice yields are reported. The average time taken to prepare 1 ha of land was as follows: Trampling: 16.3 hours/ha using 137 cattle, 3-4 operations and 5 people; Traction: 74.5 hours/ha using a pair of cattle for ploughing, harrowing and levelling.

The rice yields were 3.97 t/ha following trampling and 5.12 t/ha for ploughing. This suggests that there is a distinct advantage to farmers in using ploughs to prepare land for wet rice, compared to the use of trampling. Trampling is performed by large groups of animals (20–400 head) belonging to large cattle rearers, who charge a fee of one-third of the rice crop for land preparation. As most small-scale farmers have a few head of cattle they could train some animals for pulling ploughs. Some farmers involved in the trials are planning to fatten their trained animals for sale in 3 years.

One aim of introducing ploughs was to enable farmers to prepare land for rice planting earlier than can be achieved using trampling, which usually starts in January, some weeks after the first good rains (after cattle have gained condition). However, in 1988–89, the rains were early and no difference in planting date was observed.

Comparison of the Use of Plough, Tractor and Hand Labour in Upland Cultivation in Camplong II Village, Kupang, West Timor

A. Saleh, C. Liem and H. Marawali*

A study was conducted during the cropping season, from October 1988 to June 1989 in Camplong II Village, Kupang District, Nusa Tenggara Timur. The aim was to evaluate the labour efficiency and time consumed using three land preparation methods for upland cultivation, i.e. animal and tractor ploughing and hand labour. Two pairs of cattle for ploughing, eight farmers for hand labour and one four-wheel tractor were used. The area of 0.9 ha used consisted of 0.3 ha which had never been cultivated before and 0.6 ha which had been cultivated once. The average time taken for each method of land preparation was: Land never previously cultivated: 33 hours/ha for plough (DAP), 49 hours/ha for hand labour, 3 hours/ha for tractor; and Land previously cultivated once: 14 hours/ha for plough (DAP), 23 hours/ha for hand labour, 2.5 hours/ha for tractor.

It was concluded that there is potential for introducing animal-drawn ploughs in upland agriculture (maize, upland rice and legumes), which comprises about 90% of the total food crop area of Nusa Tenggara Timur. In this trial, some local farmers were trained to make ploughs and to work their Bali cattle. Other farmers in the area are keen to train their animals and to join in trials next year.

This abstract reports only the work on ploughing. Further studies are urgently needed on the use of DAP in cultivation (weeding) of dryland crops, which is considered to be the major constraint to improving upland productivity. Only trials on the deeper, raised coral soils are planned, and these should be in conjunction with a sound soil conservation plan.

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Feeding Practices and Introduction of Forage Legumes to Draught Animal Rearers in East Java

P.A. Yudi and M.A. Yusran*

THIS study aimed to describe the main feeding practices in two village sites in East Java, and to assess the farmer acceptance of selected forage legumes. Previous studies had indicated that there is a shortage of high quality feed available, especially in the early wet and late dry seasons, for the existing high densities of draught cattle (Sudimulyo >200 head/ha and Martopuro >100 head/ha) in the villages.

All cattle are zero-grazed in both villages. In Sudimulyo (low altitude) stored rice straw forms the bulk of the diet (70%) in the dry season, and cut native grass (76%) the bulk in the wet season (December–April). Maize stover (mainly dry) was the main supplement to straw in the dry season, with some tree leaves, in Sudimulyo. Rearers of draught animals in this village obtained three cuts of grass per year off native grassland, which is often rented exclusively for forage production and fertilised with urea. The annual yield measured from December 1988 to May 1989 was 9450 kg DM/ha (*Polytrias amaura, Andropogon caricosum, Ischaemum* spp, and others). The species most highly valued by farmers was *A. caricosum*.

In Martopuro (medium altitude and longer wet season) green grass is available for cutting and feeding all year, from road and river sides, banks of fields and other areas regarded as communal forage. The grass (*Polytrias amaura, Axonopus compressus* and other species) supplied to draught cattle is supplemented with peanut and soya bean tops, maize stover, and fresh rice straw and sugarcane tops, especially in the dry season.

The three forage legumes introduced on trial were *Glyricidia maculata, Centrocema pubescens* and *Stylosanthes hamata* (Verano). Glyricidia is intended to improve productivity of hedgerows. Centro was planted mainly on banks between fields (mainly in Martopuro), while Verano was mixed with the native grassland in Sudimulyo. Initial results suggest that grass productivity was improved by the Verano. A cultivar of *Desmanthus virgatus* is found in both villages but is little used in Martopuro, where the existence of large thickets suggests that this may have high potential. Farmers have started to plant the three legumes voluntarily, after seeing them demonstrated in the first year. Cuttings of Glyricidia have been planted on communal land by village officials. When seed becomes available, it is hoped to plant Glyricidia seedlings to obtain better tap root development and hence longer retention of leaves in the dry season.

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Lactic Acid in Working Buffaloes

D. G. Martin and E. Teleni*

HEAT stress is considered a major factor which limits the work performance of buffaloes. Under certain workloads, the accumulation of lactic acid in muscle cells could also limit the capacity of the animal to work.

Changes in plasma lactic acid concentration were monitored in *trained* and *untrained* buffaloes subjected to different workloads. Other physiological responses were measured but are not presented here.

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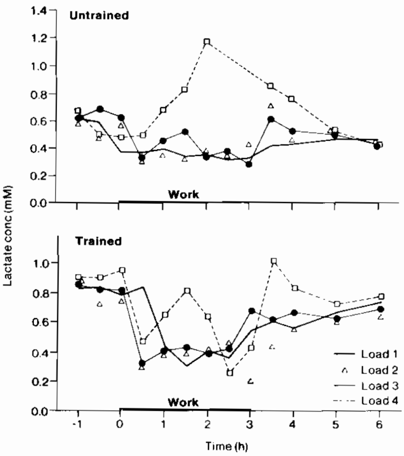
Four female swamp buffaloes (mean liveweight 363 ± 16 kg), each prepared with chronic indwelling catheters in one external jugular vein, were fed 7 kg of rice straw plus 500 g cottonseed meal/head/day. Each animal walked on a treadmill at 2.5 km/hour for a maximum of 3 hours/day, pulling a draught load equivalent to 0, 5, 8 or 11% of its liveweight. The experiment was designed as a Latin square (4 workloads × 4 periods). Animals were trained on the treadmill by pulling a draught load of 20 kg for 3 hours/day over 3 weeks. During the measurement period blood samples were taken half-hourly, for 1 hour before work, 3 hours during work and 3 hours immediately after work. Environmental parameters were also monitored.

The mean air temperature and humidity were 26.1°C and 62% respectively. The maximum temperature recorded was 33.8°C.



Loads 1, 2, 3 & 4 = 0, 5, 8 & 11% of LW
Each point = mean of 4 animals

Changes in plasma lactate concentrations in *trained* and *untrained* animals are shown in Fig. 1. The increasing mean plasma lactic acid concentration in the *untrained* buffaloes as work progressed suggests increased anaerobic metabolism in these animals.

The results suggest that *untrained* buffaloes subjected to a draught load equivalent to or greater than 11% of their liveweight might be limited in their work performance due to the accumulation of lactic acid in their muscle fibres.

Effect of Body Condition on Physiological Responses in Working Buffaloes

M. Winugroho*, S. Purba*, P. Situmorang*, E. Juarini* and E. Teleni**

In a study where the interactions between body condition, level of nutrition and ovarian activity were investigated in working buffaloes (Winugroho et al. These Proceedings), changes in respiration rates, pulse rates and rectal temperatures were also measured, and are reported in this communication.

The animals were fed and worked as previously described (Winugroho et al. These Proceedings). Measurements were carried out during the working period (80 days) on days 30, 34, 38, 41, 52 and 75. These were carried out on three groups of six buffaloes in body condition scores (on a scale of 1 to 5) of 4 (Group I), 3 (Group II) and 2 (Group III). The results are shown in Table 1.

There were no sigificant differences between the groups in their physiological responses to work, although it appeared that the animals in Group III had higher pulse rates and lower respiration rates than those in the other groups. The apparently higher mean respiration rate in fat buffaloes probably reflects the greater heat load generated by work in these animals.

It might be concluded that under the work regimes imposed on the animals, differences in body conditions do not appear to have a significant impact on the physiological responses measured.

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Table 1. Means ± SEM of rectal temperature, pulse rates and respiration rates in buffaloes of body condition scores of 4(I), 3(II) and 2(III) at rest, during work and after work.

Time measurement made		Rectal temperature (°C)	Pulse rate (no./min)	Respiration rate (no. of breaths/min)
Before start of work: 20 min	I	37.8 ± 0.4	40 ± 4	18 ± 3
	II	37.8 ± 0.3	39 ± 3	18 ± 3
	III	37.5 ± 0.2	39 ± 4	19 ± 2
After start of work: 120 min	I	39.0 ± 0.6	64 ± 9	53 ± 11
	II	39.1 ± 0.6	75 ± 15	58 ± 19
	III	39.0 ± 0.7	71 ± 9	51 ± 15
After start of work: 240 min	I	40.0 ± 0.6	73 ± 8	77 ± 19
	II	40.2 ± 0.6	82 ± 12	78 ± 22
	III	39.7 ± 0.7	81 ± 10	67 ± 18
After work stopped: 120 min	I	38.6 ± 0.4	44 ± 5	29 ± 4
	II	38.5 ± 0.4	44 ± 6	28 ± 5
	III	38.6 ± 0.5	46 ± 7	27 ± 5

Facilities for Measuring Gaseous Exchange of Large Ruminants When Working and Resting

P.R. Lawrence*

THE apparatus measures oxygen consumption, CO_2 production and methane production of animals weighing up to 1 t at oxygen consumption rates up to 20 l/min (equivalent to 6.6 kW of energy expenditure or a 1-t animal working at 7–8 times maintenance).

Gaseous exchange can be measured continuously using an open circuit system when the animal is at rest in a respiration chamber for 23.5 hours/day and when it is working indoors on a treadmill or out of doors in a circular race for periods of 3–8 hours.

Total air flow is measured by a mass flow meter for animals on the treadmill and in the respiration chamber and by a rotameter in the circular race. Gas samples from all three sections of the complex are analysed continuously for oxygen decrement (paramagnetic analyser), and for CO_2 and methane increment (infrared analyser). Signals from all analysers and the mass flow meter are sampled at 5 Hz and stored using a Metrabyte DAS 8 expansion board in an Amstrad 1512 personal computer. During an experiment, the computer program gives an 'on-line' chart recorder type graph of all inputs and afterwards allows the data to be inspected, divided into groups and filed in a form suitable for transfer to most types of commercial spreadsheet for further analysis.

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Cattle (*Bos indicus*) or Buffaloes (*Bubalus bubalis*) for Carting Loads?

R.A. Pearson and P.R. Lawrence*

BUFFALOES and cattle are the main sources of draught power in many countries in Asia. They are used for land cultivation, threshing and for transporting goods. In some areas cattle predominate, while in others buffaloes are the main draught animals. Although comparisons of their physiological responses to the environment (Mullick 1960); Prucsasri 1983 and Chikamune 1987) and to nutrition (Kennedy and Waterhouse 1987) have been reported, few impartial comparisons between the two species as draught animals have been made. Farmers in Nepal suggested that the buffaloes can pull heavier loads than the cattle but they walk at slower speeds. The differences in speed may be associated with differences in the ability of the two species to tolerate the additional heat stress associated with work, particularly when working in the sun. Cattle and buffaloes were compared when carting loads on the Terai, the flat plain in the south of Nepal, during the dry season.

Two pairs of cattle and two pairs of buffaloes carted loads, in wooden wheeled local carts, 16–17 km over the same flat route on village tracks. One team worked each day, usually in sunshine, in temperatures of 24–37°C for a total of 6 days/team. Body temperature, respiration rate and stepping rate in one animal from each pair and work done and distance travelled were measured using sensors and a data logging instrument designed to combine continuous measurements of work with measurements of physiological parameters in the field.

Buffaloes and cattle started work at speeds of 1 m/sec or more. Cattle kept this up for most of the day whereas the buffaloes showed a steady decrease in speed over the day to speeds of less than 0.9 m/sec in the last hour. Both cattle teams slowed down over the last half hour of work. Speed was significantly lower ($P < 0.05$) in the small team of oxen in this last hour than during the rest of the day. In all the teams stepping rate decreased gradually during the day with decrease in speed. Thus the pace length for any particular animal tended to remain constant. Average stepping rates in cattle were usually higher than in the buffaloes. This may account for the assumption that oxen pull loads at greater speeds than buffaloes.

The decrease in speed of buffaloes after the first hour of work in hot conditions seemed to be related to increasing body temperature, which began as soon as the buffaloes started working. Cattle in comparison did not decrease speed until later in the day, when fatigue, rather than heat stress, is likely to have been the main causative factor. Body temperature of the buffaloes increases during work. By 3.5 hours, increases of up to 3.5C° in starting values could be seen. It was necessary to stop and let the buffaloes wallow for at least 20 min to allow them to cool off before they would continue to work. During wallowing body temperature decreased to or below values seen at the start of the day's work. Unlike the buffaloes, the cattle showed changes of less than 1C° in body temperature during work. Respiration rates of buffaloes increased at least two-fold as they began panting usually after 1.5–2.5 hours. Respiration rates of the cattle could also increase up to three-fold during work. Estimated daily energy expenditures by the buffaloes and cattle on working days were similar, 1.75–1.79 and 1.74–1.78 × maintenance, respectively.

The results show that in well-fed animals of the same size there is little to choose between buffaloes and oxen in work output, provided buffaloes are allowed time to wallow on hot days. This is seen as the main disadvantage of using buffaloes for carting on longer routes. Results in this study suggested that cattle too need some rest if they have to work for long periods, otherwise work rate falls off rapidly as the animals become tired. If plenty of water is available, two factors in favour of using buffaloes for carting are their longevity and the fact that they can usually be sold for meat at the end of their working life, whereas oxen in many areas of Asia cannot easily be disposed of once they are no longer fit for work.

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Reduced Work Output of Well-Fed Buffaloes Pulling Carts in East Nepal

R.A. Pearson*

ALTHOUGH disease is likely to affect the performance of draught animals, little information is available on the quantitative effects of any disease on work output. Using equipment designed at CTVM to measure work output and physiological responses to work, it is possible to obtain quantitative information on working animals to allow comparisons between animals to be made.

This study describes the reduction in work output that occurred in a pair of apparently healthy well-fed draught buffaloes (Team A: 233 and 264 kg). Their performance was compared with that of another pair of buffaloes of a similar size and weight (Team H: 310 and 237 kg). Both teams were given adequate feed daily (2 × maintenance) and environmental conditions experienced by both teams were similar (sunshine and temperatures of 24–37°C).

Work and distance were recorded continuously and body and ambient temperature every 54 sec when each team pulled a loaded cart (carrying 70% of the total liveweight of the team) over a flat route, which involved two river crossings, on three different nonconsecutive working days.

On day 1 team A slowed down during the day's work from about 1.1 m/sec to 0.7 m/sec and the right buffalo lay down particularly in the last 2 hours. At the second river crossing, the team wallowed just before the crossing point on the river as they were reluctant to go any further once the river was nearby. On day 2 (after 7 days of rest) the buffaloes set off at about 1.2 m/sec over the first hour, but became very tired in the last 2 hours. They stopped or lay down frequently and wallowed before the second crossing point. Both buffaloes refused food that evening, but had eaten the next morning. On day 3 (after 8 days of rest) the buffaloes walked slowly (about 0.8 m/sec) and were reluctant to pull the cart. In view of their apparent weakness the route was reduced to 14.7 km.

Team H worked steadily and consistently each day and rarely stopped. Over the 3 days the team showed a progressive increase in the speed at which they worked, from about 0.9 to 1.1 m/sec. In contrast to team A they had only 3 days and 4 days rest between each of the working days. Table 1 summarises the performance of each team on each day.

Body temperature was recorded from one buffalo from each team. Increases in body temperature during a day's work ranged from 1.5 to 5.5C°, and was higher in the buffalo from team A than from team H. Blood samples taken from each buffalo at the end of the study showed team A to have PCVs of 23 and 27% compared with PCVs of 33 and 37% in team H.

Although this study reports only a single instance of reduced work output it does illustrate that a rapid decline in work output can occur in apparently healthy buffaloes. That it was not resolved by adequate nutrition and rest periods between working days, and was associated with some degree of anaemia, suggests that ill health was the cause. Work clearly precipitated the situation as the buffaloes becam[illegible] gressively weaker over the 3 days work. It is suggested that the decline in wor[illegible] associated with a parasitic or disease infection.

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Table 1. The performance of two teams of buffaloes (A and H) carting loads on three different nonconsecutive days over flat land.

	Distance travelled (km)	Work done (kJ)	Length of working day (hours)	Time spent wallowing (min)	Avg speed when working (m/sec)	Avg power output/ days work (W)
Team A						
Day 1	16.41	4529	5.8	19	0.83	217
Day 2	16.48	4548	5.8	48	0.91	216
Day 3	14.69	4054	6.1	36	0.74	185
Team H						
Day 1	16.42	4927	5.7	26	0.87	240
Day 2	17.05	5114	5.6	35	0.94	253
Day 3	17.08	5124	5.1	25	1.02	276

Effect of Exercise on Body Weight Change and Voluntary Intake of Barley Straw in Cows Fed One of Three Dietary Supplements

R. Matthewman*, A. Pearson* and J. Oldham**

TWELVE pregnant, lactating suckler beef cows (Hereford × Friesian) in three dietary treatment groups were walked for 3 hours/day for three periods of 5 days each divided by two nonwalking days. The cows walked approximately 10.6 km each day and climbed a height of 480 m each day. This expenditure was estimated to be equivalent to an energy expenditure of 12 MJ ME/ day. The three diet supplements were a high starch diet (HS2) based on 86% maize, a high protein diet (HP) based on 30% fishmeal/30% soya and a digestible fibre diet (DF) based on 87% molasses sugar beet pulp. Four kilograms of each supplement was fed to each cow each day and unchopped barley straw was fed ad libitum to all cows. The experimental design was 3 weeks nonwalking, 3 weeks walking and 3 weeks nonwalking (NW–W–NW).

The three treatment groups were balanced for body weight at the beginning of the experiment. Mean body weights (kg) at the beginning were 501 (HS2), 506 (DF) and 504 (HP). Mean weights at the end of the 9-week experiment were 510 (HS2), 510 (DF) and 555 (HP). Cows fed diet HP were significantly ($P<0.001$) heavier than cows fed diets HS2 or DF and HP cows gained weight faster than other groups ($P<0.05$). All diet groups lost weight when they walked. Mean losses (kg) were 10 (HS2), 5 (DF) and 4 (HP). These results were similar to those of Ffoulkes (1986) and Winugroho (1988) who measured weight losses in working female buffaloes.

Neither diet nor exercise had a significant effect on voluntary intake of barley straw. Cows fed diet HP ate an average of 8% more straw than cows fed other diets. A nonsignificant reduction in straw intake occurred when animals walked. The maximum response to exercise was seen in HS2 cows which had a reduced intake of 12.4% in the 3-week walking period. These results were similar to those of Barton (1987) who found no increased intake of rice straw in working cows in Bangladesh, but differ from those of Ffoulkes (1986) who found a positive effect of work in food intake.

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Effect of Dietary Heat Increment on Physiology of Working Animals

B. Bakrie*, R.M. Murray** and E. Teleni**

THE difference in ability to withstand the extra heat load during work between cattle and buffaloes causes a dissimilar physiological response to work by these animals. This to some extent may relate to the lower capacity of buffaloes compared to cattle to dissipate extra heat from the body, due to the former possessing fewer sweat glands and hair follicles (Hafez et al. 1955). Another source of internal heat load is dietary heat increment. A study has been conducted to investigate the effect of this heat load on working performance of cattle and buffaloes.

Four cattle and four buffaloes were fed either a roughage (high heat increment) diet (diet 1) or a concentrate (low heat increment) diet (diet 2), designed to provide the same metabolisable energy (ME) intake. Rations were formulated from hammer-milled sorghum hay plus urea and mineral supplement mixture and from finely ground maize. The animals were subjected to work by walking on a treadmill at a speed of 2.3 km/hour for 3 hours/day and pulling a load of 20 kg. Rectal temperature (RT) and respiration rate (RR) were measured immediately before work and at 60-min intervals during work until 3 hours after work.

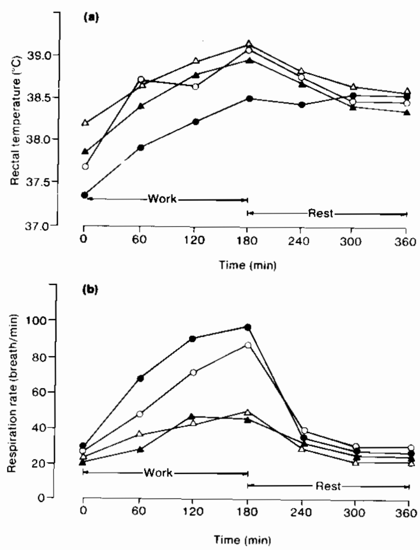

Fig. 1. Rectal temperatures (a) and respiration rates (b) of working cattle (◇, ◆) and buffaloes (○, ●) given either roughage (◇, ○) or concentrate (◆, ●) diets.

Diet had little effect on the physiological responses of cattle either at rest or during work (Fig. 1). Neither were there any differences between the roughage and concentrate diets in the physiological responses by buffaloes at rest. However, there was an initial effect of diet on the RR of buffaloes during work with rate increasing more rapidly when consuming the concentrate diet. These differences tended to disappear after 3 hours' work. Also during work there was a significant difference between the RT of buffaloes on different diets, those receiving the concentrate diet having lower temperature. While the higher RR of working buffaloes on the

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concentrate diet may have contributed to the lower RT of the animals on this diet, the lower heat increment of the maize would indicate that working buffaloes may benefit from receiving diet of low heat increment.

It is suggested that although buffaloes are claimed to utilise high fibre diet better than cattle (NRC 1981), it seems beneficial to provide a less fibrous diet when these animals are required to work in relatively hot conditions.

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Resting Energy Consumption of Working Oxen

P.R. Lawrence*

THREE well trained Brahman × Friesian oxen (5 years old, liveweights 615–750 kg) were given a straw-based pelleted diet at levels calculated to provide either 1.4 × maintenance (high level) or 0.7 × maintenance (low level).

The metabolic rate (MR) of each ox as calculated from its gaseous exchange was measured continuously for 5 days. The ox was kept in a respiration chamber except during the period 0930–1600 hours on the third day when it worked at a rate sufficient to raise its MR to 3.5 × maintenance by pulling a load round a circular race. Each ox underwent this treatment twice at both levels of feeding.

The MR during the 17 hours following work on the third day was higher than the average rate during the same time of day on the other 4 days of the week by 8.2%, when the oxen were fed at the low level but only by 0.6% on the high level. This difference was significant at the $P < 0.01$ level.

The same three animals fed at maintenance were used to approach the problem of underlying rate of energy consumption whilst working in two ways:

The first was to give the animals a constant load to pull at various speeds, to extrapolate energy consumption back to zero speed and compare the extrapolated MR with the average daytime value on nonwork days (y). A regression equation of all values gave $y = 24.2x + 1.04$ ($n = 81, r = +0.90$) where x = speed in m/sec, which implies that the underlying average MR is 4% higher and not significantly different on working compared with nonworking days.

In the second approach, the MR was simply measured between bouts of work after the animal had been standing still for at least 10 min. The average value was $y = 1.26$ ($n = 18$, SD = 0.08).

Conclusions (a) On poor quality feed oxen use extra energy after work presumably to resynthesise food reserves.

(b) Methane production is increased when oxen on high levels of feed work. On lower levels the rate of production is the same whether the oxen work or not.

(c) The RQ of oxen falls steadily during work and often reaches values of 0.7 indicating that the animals are using their fat reserves for energy.

(d) At maintenance level of feeding work does not increase the maintenance component either during or after work.

(e) The MR whilst standing during the working day is about 26% higher than on nonwork days. This should be taken into account when applying data from 'laboratory' studies which often use MR when standing as a base line.

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Regression of Body Weight on Body Measurements in Buffaloes

H. Prasetyo and R. Dharsana*

BUFFALOES as draught animals play an important role in rural areas. The minimum availability of scales for weighing animals in villages often presents problems in a transaction or in judging the potential of the animals. Methods of estimating live body weight (BW) from measurements of body surface would be useful, and the relationships have not been established in buffaloes.

Chest girth (CG) was measured using a measuring tape as the circumference of chest just behind elbows. Body length (BL) referred to the distance between point of shoulder and point of pin bones. The third measurement, height at withers (WH), was taken at the highest point above forelegs. Measurements were made only once, but twice or three times would be preferable to assure a higher precision.

Observations were obtained from 77 female and 12 male animals with BW ranging between 113.5 and 487 kg. Regression equations and correlation coefficients (r) were calculated between BW and CG, BL, and WH.

In females, BW had a higher correlation with CG (r = 0.90) than with BL (r = 0.77) or with WH (r = 0.74). The regression equation that fitted best was BW = -457.5 + 4.5 CG ($P<0.001$).

In males, the result was not very conclusive due to the small size of the sample. There was an indication that BW had a higher correlation with BL (r = 0.96) than with CG (r = 0.91) or with WH (r = 0.78). The fitted regression equation was BW = -501.3 + 6.6 BL ($P<0.001$).

The result on female animals is of importance due to the fact that the females represent a major portion of the population in the villages. The different results between males and females are not clear. More data on males are needed.

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Interaction Between Body Condition, Level of Nutrition and Ovarian Activity in Working Swamp Buffalo

M. Winugroho, P. Situmorang* and E. Teleni**

IN an experiment with *Bos indicus* cattle, Teleni et al. (1988) showed that animals in reasonably good body condition (mean liveweight of 338 kg) ceased cycling when they lost approximately 17% of liveweight. This loss was equivalent to a reduction in body fat: protein from approximately 0.96 to 0.24 (Teleni, unpublished data).

This communication reports on the effects of body condition, current nutrition and work on ovarian activity of swamp buffaloes. Twenty-four mature female buffaloes, exhibiting normal ovarian activity were divided into three groups of eight. All animals were offered chopped fresh rice straw ad libitum. Groups I and II were also given supplements of a commercial concentrate (Bk) at the rate of 4 and 2 kg/head/day respectively. At the end of 90 days (Period 1) the mean liveweights of animals in each group were 370, 344 and 288 kg for Groups I, II and III, respectively. Corresponding body condition scores (on a scale of 1 to 5) were 4, 3 and 2 and

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cyclic activity in animals in Group III, as determined through rectal palpation, had ceased. Means of peak progesterone concentrations over Period 1 were 3.3 ± 0.8, 3.3 ± 0.7 and 1.1 ± 0.6 ng/ml for Groups I, II and III, respectively.

In Period 2 (80 days), animals in Groups I, II and III were given Bk supplements at the rate of 2.5, 2.0 and 1.0 kg, respectively. In addition half the number of animals in each group were subjected to work by pulling sledges (approximate draught force of 72 kg) for 4 hours/day. Across groups, the means of peak progesterone concentrations in plasma were 3.1 ± 1.5 and 3.0 ± 1.1 ng/ml for the working and nonworking animals, respectively. Normal cycling patterns displayed by animals were 81% for the working animals and 88% for the nonworking animals. Mean liveweights at the end of Period 2 were 380, 341 and 290 kg for Groups I, II and III, respectively.

Results of this experiment suggest that depletion of body reserves is a major determinant of ovarian function and that work per se does not appear to have any significant effect. Animals with body condition score of 2, based on the scale used, would most likely have abnormal ovarian function. The difference in mean liveweight between animals with body condition score of 4 or 3 and 2 was 82 or 56 kg, suggesting that if animals in Groups I and II were to lose, respectively, 22% and 16% of liveweight, they would cease cycling. The data are consistent with that reported for cattle (Teleni et al. 1988).

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Body Weight Changes and Feed Supply Problems in Draught Animal Enterprises: An Example from Padamulya Village, Subang, West Java

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A monitoring study (December 1986–June 1988) of cattle and buffalo body weight showed that, on average, animal body weight steadily increased throughout the year, and the young animals' body weight increased faster than that of adult animals. This was despite the fact that 95% of cattle rearers and 80% of buffalo rearers in Padamulya reported that they had serious problems in feed supply, due to limited grazing area. Most of the land is planted to crops in the wet season and no forages are traditionally planted.

Farmers were able to overcome the feed supply problems by seeking and cutting feed from areas outside the village, so that their animals gained some weight throughout the year. The labour involved in feeding was, however, very high at certain times of year, e.g. an average of 6–10 person-hours/day in herding plus 2–6 hours for handfeeding in the dry season. The high labour demand may be a serious deterrent to rearing draught animals for many of the farmers (73%) who do not rear at present. The labour involved in rearing animals could result in lost income from labour from off-farm sources. Improved forage supplies and preservation of straw are seen as important ways of attempting to reduce the labour costs in feeding draught animals in West Java.

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Evaluation of Different Buffalo Genotypes for Meat, Milk and Draught Production

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THERE is a paucity of information on the comparative performance of different breeds and strains of buffaloes throughout the world. Using existing genetic variation between breeds and strains of buffalo offers the most rapid means of genetic improvement through crossbreeding. The extent of the existing variation and the relative performance of crossbreds can only be assessed by comparative evaluation of different genotypes in a range of environments. In 1985, ACIAR developed a project to undertake such studies, based on proposals from an ACIAR workshop and ASEAN.

The aim of the project is to undertake a program that will encourage research institutes in Southeast Asia, under simulated management conditions of smallholders to (a) undertake comparative studies on feed utilisation between breeds and strains; (b) study differences in reproductive performances; and (c) study variations in draught power.

Further aims are to establish a mechanism for coordinating and transferring research findings between cooperating institutes, and to encourage their application in smallholder systems to improve productivity.

Comparative Studies in Reproduction In Sri Lanka research is under way to study the intercalving interval of Lanka and Murrah buffaloes under small farmer management in the dry zone with and without supplementary feeding. Although the feed supplement decreased the intercalving interval in both genotypes the Lanka buffalo had a shorter interval than the Murrah under both regimes.

In Malaysia investigators are studying the reproductive performance of F_1 Swamp × Murrah, Murrah and Swamp buffalo under two nutritional regimes, both of which were relatively 'high' (irrigated pasture with and without palm kernel cake). Supplements had no effect in this situation and the calving interval was over 300 days less in the F_1 than in either of the parental breeds.

Philippines researchers are collecting comparative information on Carabao, Nili-Ravi × Carabao and Murrah × Carabao. Whilst only relatively small numbers are available as yet trends are emerging. Crossbreds reach puberty 1 year earlier than Carabao and calve at 4 rather than 5 years of age. They also produce substantially more milk.

Thai and Indonesian scientists are generating F_1 Murrah × Swamp calves in Thai and Indonesian villages. Much is being learned about the technology by which crossbreeding can be made possible on a large scale using oestrous synchronisation and AI technologies. In Thailand large numbers of crossbred calves have been generated and growth rates are being compared (reproduction when the F_1 progeny are old enough) and in Indonesia the generation of F_1 calves is in its first year.

Comparative studies on growth and nutrition In Malaysia studies are being done on digestibility and rumen function in Swamp, ¼ Murrah and ¾ Murrah buffaloes on different diets. Although the Murrah-infused genotypes grew faster than the Swamp there were no significant differences between them in feed intake, or in rumen degradation and fermentation characteristics. Studies on the relative maintenance requirements of the three types will start in 1989.

The Thai researchers are collecting growth rate information on Swamp and ½, ¾ and pure Murrah genotypes as well as data to assess heat tolerance. At one location ½ and ¾ bred Murrahs grew faster than pure Murrahs and at another location Swamp grew as fast as the crossbreds. However these findings are being verified by comparing Swamp, ½ Murrah and ¾ Murrah in the second environment. Differences between the genotypes in physiological measurements related to heat tolerance were small.

In Thai villages F_1 crossbreds (Murrah and Swamp) apparently grow faster than the Swamp. A similar result has occurred in Philippine villages. The F_1 Murrah and Carabao Nili-Ravi × Carabao are growing faster than the Carabao and as more numbers come on stream this trend will become clearer. It is of interest that Carabaos at the same age appear to be heavier on the smallholder farms than at the UPLB farm.

Draught Power There is no work at present on draught power but comparisons of the crossbreed with Swamp types are planned in the Philippines and in Thailand. It is anticipated that crossbreds generated by the team in Indonesia will become available for DAP studies by 1992–93.

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Draught Animal Power Implements of East Java

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THE aim of this study was to describe the size, shape and weight of implements used in draught animal power of East Java. A survey was carried out at three village sites in Pasuruan, i.e. Sudimulyo, Dandang Gendis and Martopuro. At each site, six samples of each main type of implement were studied. Implements described were levellers and dry and wet land ploughs. Measurements of size, shape and weight of yoke and implement were recorded and the implements were further described with photographs. The dimensions of length, width of the yoke and length of beam, handle height, length of plough, width of plough wing and height of plough wing, were taken on the dry and wet land ploughs. For the levellers, length, width and handle height were recorded.

Later, a larger study was carried out in four districts: Malang, Probolinggo, Lunajang and Blitar, where the same range of implements was described. The size of levellers and yokes in villages in Pasuruan District were significantly different ($P<0.05$). Size of ploughs in three villages did not differ. The shape of ploughs in five districts in East Java differed widely, but the yoke and leveller were the same. Size, shape and weight of implements in Blitar District were different ($P<0.05$) to that in other districts. A similar study conducted in Madura, showed distinct differences between the type of ploughs used in different districts.

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Effect of Puddling on the Draught of Soil After Drying

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LOWLAND rice is a major crop in many Asian countries and rice-based cropping systems with other crops following the rice are becoming popular. Much emphasis for research into these systems has been on 'turn-around' period, that time between harvest and when the soil is ready to till, as well as what level of ploughing is necessary.

In an experiment in which rice was grown after puddling the soil different amounts, the turn-around was determined by measuring the time it took for the soil to dry to the lower plastic limit water content (Taylor 1972) after rice harvest. It was then ploughed to a depth of 10 cm and draught measured. Two soils were used in this experiment: a clay (75% clay sized particles)

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and a loam (22% clay sized particles), and because these were at different locations in East Java ploughing at one site was done by oxen and the other by water buffalo.

The length of the turn-around period was determined by the degree of puddling and soil type. The degree of puddling was imposed by ploughing and harrowing the soil under water a number of times (P0, P1, P2, and P3). The values were: Loam P0, 12 days; P1, 17 days; P2, 22 days; P3, 27 days; and Clay P0, 14 days; P1, 20 days; P2, 26 days; P3, 36 days. The reason for the longer period for the puddled soil to dry relates to interparticle bonds being broken and water being held between clay plates (Tranggono 1988).

Draught was measured with a dynamometer (Eijkelkamp, the Netherlands) attached to the drawbar of the plough with the aid of a yoke. Ten runs per plot were done to determine the final draught. The results were: Loam P0, 0.30 kN; P1, 0.51 kN; P2, 0.64 kN; P3, 0.76 kN; and Clay P0, 2.94 kN; P1, 2.25 kN; P2, 1.52 kN; P3, 1.51 kN. The draught force was lower for the loam soil; it increased with puddling in the loam but decreased with puddling in the clay. Clay type (montmorillonite) (Raven et al. 1988) and orientation are implicated in this change in draught.

Other soil properties measured, i.e. penetration resistance of the soil and tensile strength of air dry aggregates sampled after this ploughing support these results. The values of these strength parameters were less in the loam than in the clay, and in the loam they increased with puddling while in the clay they decreased with puddling.

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Bull Subsidy Scheme for West Java: A Demonstration/Trial in Tanjungwangi Village, Subang

T. Chaniago and Santoso*

A shortage of mature bulls is known to be a serious constraint to improving productivity of draught animal enterprises in many West Java villages. This is particularly critical in medium altitude villages (100–500 m) where the density of buffalo (or cattle) is low, cropping percentage is high and there is little communal grazing area (Santoso et al. 1987). Some villages have no mature bulls, and rearers must rely on animals mating with bulls from other villages. Estimates of calving rates in buffalo and cattle in West Java villages range from 10 to 70% (Petheram et al. 1982; Sumanto et al. 1987).

The reason for bull shortage is that farmers prefer to keep cows to bulls, because cows can produce calves as well as work. In addition, cows are considered easier to train and to handle while working. In the past farmers have been able to rely on their cows mating with other farmers' bulls. Today, however, fewer and fewer farmers feel that they can afford to keep mature male animals. Often the only male animal available for breeding in a village is a young or small bull which has not been sold because of its inferior condition and size.

Artificial insemination schemes have been set up in a few areas of West Java, but these have been notably unsuccessful, especially in swamp buffalo areas. In any case, AI can only reach

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a small fraction of the farmers. The alternative of establishing 'subsidised sire' schemes would appear to be much less expensive and more practical than AI.

In an attempt to test the feasibility and farmer opinion of such a scheme, a farmer in Tanjungwangi village was subsidised (Rp100 000) for 1 year to keep a bull (which he would otherwise have sold at 18 months of age) for the use of all farmers in that village. The farmer could use the animal for work. No service fee was charged, as this is not traditional in the area.

In 1 year, seven farmers in the village were known to have used the bull, although the total number may have been much higher. These farmers and others in Tanjungwangi are very keen for the bull subsidy scheme to be continued in the second year. The fact that the calving rate in this village rose from 33% in 1987–88 to over 60% in 1988–89 is further evidence that such a bull scheme could result in valuable improvements in animal production in West Java. The urgency of this matter cannot be overstressed, especially when the potential ill-effects of negative selection through breeding with the poorest bulls are considered. Another matter requiring urgent intervention, revealed by this study, was that knowledge of principles of animal reproduction is poor; some farmers believe that bulls are not required for conception.

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Weights and Prices of Large Ruminants at Purwodadi Market, Subang, Indonesia

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Most smallholder livestock are sold at some point in their life — and often traded more than once — to meet income needs of their owners. Relatively little information is published on the prices paid for cattle and buffalo and, in particular, the important price:weight:age relationships. Knowledge of such relationships is essential for realistic farm-level budgets.

The livestock market at Purwodadi, Subang, was observed from October 1988 to January 1989. Two enumerators attended each market day, equipped with a set of electronic cattle scales. They recorded the type, sex, age and weight of each large ruminant offered for sale. If an animal was sold, the price paid was asked of both buyer and seller.

A total of 701 cattle and 40 buffalo were offered for sale during the period, of which 94 cattle and one buffalo were sold. In total, twice as many females were offered as males with this ratio increasing for stock of 4 years or older. Some unsold cattle may be offered again for sale three or four times; many others are transferred to the larger market at Bandung. Most animals are traded by *blantiks*, or animal brokers, and it is possible that local merchants regard Purwodadi as a test-market for sales in Bandung.

Young animals of either sex, including calves and yearlings, find the readiest sale, usually for rearing on another farm. Relatively few animals are bought for slaughter although this is difficult to check.

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Price:weight relationships showed an expected trend of higher weights receiving higher prices. However, the variation in price at any particular weight was pronounced. Many factors may contribute, including the general condition and health of the animals. It may also be related to the relative bargaining strengths of the traders and their methods of appraisal: looking, pummelling and squeezing. A larger data set would be required to test these important variables.

There is a tendency for price/kilogram to drop with increasing age. The correlation is statistically weak and further confounded by problems of estimating age with accuracy, particularly for young, growing cattle.

Data obtained will provide an excellent resource for farm budget purposes. Realistic top and bottom prices can be inferred for cattle weights up to 350 kg, but not for buffalo. The most important lesson is the riskiness of rearing large ruminants: the price obtained depends upon both the merits of the animal and the skills of the participating traders. Any farm budget incorporating cattle or buffalo should be subjected to a sensitivity analysis of $\pm 25\%$ of the sale price when predicting the income, and profit, that derives from animal management.

No scales are provided in Purwodadi market, as is the case in many parts of Indonesia. The installation of cattle scales would probably narrow the price variation and reduce uncertainty for both buyers and sellers.

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