Coping with feed scarcity in smallholder livestock systems in developing countries

International Livestock Research Institute

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The University of Reading

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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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editors:
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Foreword

Livestock are important assets to the rural poor in developing countries as they have multiple roles in sustaining the livelihoods of smallholder farmers. They provide food and essential nutrients for cognitive development of children and the general welfare of humans. Their manure helps maintain soil fertility contributing to the overall sustainability of the farming enterprise. Livestock also provide poor farmers with employment opportunities and a flexible reserve of cash that can be used to meet the family needs for health, food security and education and to purchase farm inputs. In many rural societies poor women derive their income from livestock keeping. All these roles are frequently impaired by insufficient supply of feed.

This publication addresses the problem of feed scarcity and options to overcome undernutrition of livestock in smallholder systems in developing countries. The publication has its origin in an initiative taken in 1999 at the International Livestock Research Institute (ILRI) led by Bill Thorpe, Paschal Osuji, Jon Tanner and Jeroen Dijkman. The initiative was aimed at identifying opportunities for improving small-scale market-oriented dairy production through improved nutrition. The then Institute for Animal Science and Health, ID-Lelystad (currently the Animal Science Group of Wageningen UR) of The Netherlands, the Department of Agriculture of the University of Reading, United Kingdom, and the Swiss Federal Institute of Technology Zurich (ETH) joined ILRI in this effort. The initiative was supported by the Organization of Petroleum Exporting Countries (OPEC) Fund, the Government of the Republic of South Africa and the Systemwide Livestock Programme of the Consultative Group on International Agricultural Research (CGIAR).

As part of this joint effort, the collaborating institutions commissioned a review on undernutrition in smallholder ruminant production systems in the tropics. The objectives of the review were: 1) to describe the major nutritional constraints to ruminant meat and milk production systems in the tropics and 2) to identify ways of overcoming undernutrition of ruminant livestock in the tropics. Following this review, a workshop on ‘Coping with feed scarcity’ was organised by ILRI. The workshop was held in Addis Ababa, Ethiopia on 14 to17 June 1999. The objectives of the workshop were: 1) to present and discuss the review on undernutrition in smallholder ruminant production systems in the tropics, 2) to present and discuss case studies on undernutrition of ruminant livestock in the tropics, the physiological and metabolic implications of undernutrition and the social and economic factors that influence the nutrition of livestock in farming systems in the tropics, and 3) to outline the contents of a research proposal on undernutrition in smallholder ruminant production systems with the overall goal of improving the livelihoods of livestock and crop–livestock farmers through optimised use and enhanced availability of feed resources for ruminants.

Between 2002 and 2003 the editors contacted the participants of the workshop and edited the papers presented at the workshop and the review paper, which had remained as a working document. These papers are presented in this publication. The publication is divided into four parts. The first part contains the review commissioned by the participating institutions; the second covers case studies of undernutrition of ruminant livestock in tropical developing countries; the third covers physiological and metabolic aspects of undernutrition in livestock and their implications for feed evaluation; and the fourth discusses socio-economic aspects related to undernutrition.

The funding provided by the OPEC Fund, the Government of South Africa and the sponsors of the CGIAR, as well as the feedback from the authors of the papers who make this publication possible, are gratefully acknowledged. ILRI and the editors thank Tesfaye Jemaneh for editing, Meron Mulatu for typesetting, Apollo Habtamu for assisting with design aspects of the publication and Richard Fulss for publishing arrangements. The papers in this publication reflect the views of the authors, not those of the institutions involved and the funding agencies that supported this initiative.

Review of undernutrition of ruminants in the tropics

Review of undernutrition in smallholder ruminant production systems in the tropics[1,2]

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Summary

Developing countries continue to face the challenge of increasing poverty and depleting asset base of their predominantly rural populations. In sub-Saharan Africa (SSA) alone, over 70% of the population now live below the poverty line, and in South Asia the number of poor people exceeds 500 million. More than 160 million children worldwide are protein malnourished. Over two-thirds of the world's 1.3 billion poor live in rural areas and rely on agriculture for a significant part of their livelihoods. Livestock are important assets to the rural poor and play a critical role in both the sustainability and intensification of agricultural productivity in most farming systems. They provide food and essential nutrients for cognitive growth of children and the general welfare of humans. Their manure helps maintain soil fertility and they contribute to the overall farming enterprise in terms of income and employment. Livestock also provide poor farmers with a flexible reserve and access to markets. In many rural societies poor women derive their income from livestock keeping.

The objective of this review paper was to describe the major nutritional constraints to ruminant meat and milk production systems in the developing world and explore ways of overcoming undernutrition in the tropics. Issues addressed in this review include causes of undernutrition and environmental implications, adaptation by the ruminants to it, manipulative strategies to cope with feed scarcity in smallholder ruminant production systems and modelling of undernutrition in ruminants. This review paper has evolved as a working paper over the last few years, and represents the contributions of many staff members of the International Livestock Research Institute (ILRI) and their collaborators, which are acknowledged in this publication.

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[1] This review was commissioned by ILRI with contribution by ID-Lelystad, The Netherlands; University of Reading, UK; ETH, Switzerland; OPEC; SLP and the Government of South Africa.

[2] Contributions to the review by Ad van Vuuren, Agnes Odenyo, Azage Tegegne, Eva Saarisallo, Graeme McCrabb, Jeroen Dijkman, John Topps (deceased), Michael Kreuzer, Salvador Fernández-Rivera and William Thorpe are appreciated.

Introduction

Consumption of animal products in developing countries is substantially less than in the developed countries, Table 1 (FAO 1992a). It is desirable that the human diet, especially that of young children, should contain either liquid milk or milk products (van Steenberg et al. 1978). Where other feeds are in short supply, the fat obtained from milk can be a rich source of energy, thus making high-fat milk desirable.

Table 1. *Per capita consumption of meat, milk and fish in 2000 (kg/year).*

Region	Meat	Milk	Fish
World	32.9	75.0	13.1
Developed	81.6	200.0	26.8
Developing	17.7	36.6	8.8
Africa	11.4	27.5	8.0
Latin America	41.1	93.9	8.6
Near East	19.6	60.7	4.4
Far East	15.1	27.0	9.4

Source: FAO (2002).

The lack of animal products is not due to a lack of animals *per se* (e.g. Africa has 12.7% of human, 13.6% of cattle and buffalo, 28.9% of goat, 19.2% of sheep and 73.4% of camel population of the world), but due to low productivity (Qureshi 1996). There are a number of reasons for this as listed in Table 2 of which insufficient and inefficient use of feed is the major one (Kreuzer 1997).

Table 2. *Common reasons for undernutrition of ruminants in tropical countries.*

Water supply too low
Low amount of feed available
Low feed quality
Low feed intake
Lack of knowledge of feed quality and of animal requirements
Deficient and imbalanced diets (energy, protein (including non-protein N), minerals, vitamins)
Increasing use of highly susceptible high-yielding breeds and crossbreds to replace indigenous breeds in areas with inadequate feed resources

Source: Kreuzer (1997).

In most developing countries agriculture is the major source of subsistence, employment and income. Most farms are fragmented and interdependent smallholder mixed crop–livestock systems. Increasing population and diminishing land resources (buildings etc.) are creating a growing number of landless people who also have to produce their own subsistence.

In developed countries livestock are kept generally for mono- or dual-purpose. In developing countries, especially those with weak economies, livestock, particularly cattle, are multi-purpose. 'Non-productive' cattle have a high socio-economic and cultural value for which reason farmers are often reluctant to slaughter cattle, while relying on increased milk consumption, as the option that enables them to improve their livelihoods, without reducing the size of their herds. There is a need also to ensure affordable food for rapidly increasing poor urban populations. It is estimated that 47.2% of Africans will be urban dwellers by the year 2015, up from 34.4% in 1995 (UN 1995).

When promoting ruminant milk production in developing countries, other species of importance must also be considered. Buffalo, for instance, has a clearly defined role in Asia, especially in the more humid areas. Goat is also a major producer of milk, particularly in areas too dry to support larger species. Contribution of sheep (in the Mediterranean area and the Middle East) and camel (in the North-East and East Africa) should also be noted (Field 1998). Total milk production is shown in Table 3 and the predicted availability of milk in Table 4.

In the last 50 years most developing countries have seen a rapid increase in their human populations. Despite birth control measures, the population of Africa is predicted to increase by approximately 70% by the year 2020 (Table 3). This is because infant mortality rates have fallen (non-AIDS related conditions), a large proportion of the population is young and life expectancy (ignoring AIDS) is increasing. If the rate of increase of population and milk production happened as predicted, milk available per capita in Africa will fall from 27.5 to less than 24 kg per year in 2020.

Global changes in consumption of livestock products, for example, increased beef consumption in China, could reduce grain availability in Africa (Delgado et al. 1998). Livestock systems, therefore, will have to change if the production targets are to be met in a sustainable way. This can be achieved by the efficient use of existing feed resources and identifying new feed resources. If livestock development is to contribute to poverty reduction it must result in cheaper and/or more available food for the poor, increased employment and enhanced livestock productivity (Holden 1998). Qureshi (1996) noted that it is the duty of research and development agencies to develop and deliver the required technologies so that animal production remains the fastest growing agricultural sector.

The objectives of this review are to describe the extent to which undernutrition constrained ruminant livestock production, and to identify options for how existing feed resources may be better managed to overcome it.

This review has a major focus on understanding the implications of undernutrition on the development and lifetime productivity of exotic, crossbred and local dairy genotypes, but will not necessarily exclude discussion of other classes of ruminant livestock. The following issues are addressed in the review:

1. Justification: describing current livestock systems and practices, and the role of livestock in the farming system; describing available and other feed resources
2. Nutrition: plane of nutrition; specific nutrients; physiological state of the animal; lifetime performance; potential for increasing the total nutrients available from the feed resource; nutrient sparing strategies used by livestock to alleviate stress (including that caused by climate and water shortages); animal health; identifying researchable issues

3. Modelling: current status of available models for predicting dairy production in the systems; identifying gaps in knowledge
4. Recommendations: identifying the likely roles of national research systems, advanced research institutes, and extension and development agencies in carrying out the required research and dissemination of information to smallholder farmers.

Table 3. *Human population (× 10^6) and the production of cattle, buffalo, sheep and goat milk (× 10^6 t).*

	1990	1995
Population		
World	5282	5687
Africa	629	719
South America	292	317
India	850	929
Milk production	1989–91	1995
Cattle		
World	479	468
Africa	15	16
South America	32	40
India	26	32*
Buffalo		
World	41	50
Africa[1]	1.2	1.6
South America	–	–
India	26	31*
Sheep		
World	7.8	7.9
Africa	1.4	1.5
South America[2]	0.03	0.03
India	–	–
Goat		
World	9	10
Africa	2	2
South America[3]	0.2	0.2
India	1.6*	1.9*

* Unofficial figure.
1. Total production in Egypt.
2. Total production in Bolivia and Ecuador.
3. Total production in Bolivia, Brazil, Chile, Ecuador and Peru.
Source: FAO (1996).

Table 4. *Predicted human population (× 10^6) and production of cattle, buffalo, sheep and goat milk × 10^6 t) in 2000, 2010 and 2020.*

	1990	1995–96	2000	2010	2020
Population					
World	5282	5727	6091	7001	7911
Africa	629	728	808	1008	1208
South America	292	319	339	389	439
India	850	936	1004	1174	1344
Milk production	*	**			
Cattle					
World	479	466	453	427	401
Africa	15	16	17	19	21
South America	32	40	48	64	80
India	26	32	38	50	62
Buffalo					
World	41	50	59	77	95
Africa[1]	1.2	1.6	2	2.8	3.6
South America	–	–	–	–	–
India	26	31	36	46	56
Sheep					
World	7.8	7.8	7.8	7.8	7.8
Africa	1.4	1.5	1.6	1.8	2
South America[2]	0.03	0.03	0.03	0.03	0.03
India	–	–	–	–	–
Goat					
World	9	10	11	13	15
Africa	2	2	2	2	2
South America[3]	0.2	0.2	0.2	0.2	0.2
India	1.6	1.93	2.26	2.92	3.58

* 1989–91, ** 1994–96.

1. Total production in Egypt.
2. Total production in Bolivia and Ecuador.
3. Total production in Bolivia, Brazil, Chile, Ecuador and Peru.

Source: FAO (1996).

Justification

Background

In developed countries cattle are usually kept to produce milk, meat or both. In developing countries, particularly in Africa, the supply of draft power and manure are often seen as of greater importance than milk production, with meat being the seventh, or lowest ranking reason for keeping cattle (Gapare 1988). In India, selling cattle dung for fuel to urban centres can supply up to 60% of the income of a poor village family (Jasiorowski and Quick 1987). Milk is an acceptable production pathway in some developing countries, where religion and/or culture do not permit consuming cattle meat. In other countries meat is considered as a valuable terminal output from cattle.

Methods of feeding cattle vary from cut-and-carry to pen-fed animals in the mixed crop–livestock systems. However, regardless of method of feeding, most ruminants in the tropics are partially dependant on crop residues for feed, and contribute manure (Powell et al. 1998) and draft power (cattle and buffaloes) into the arable sub-sector. Early plowing, often related to cattle ownership, increases the area of land cultivated (Powell et al. 1998) and crop yield per hectare (Shumba 1984). The exceptions are likely to be found in the peri-urban sector, where feed is transported in, but manure is likely to be used close to the point of production (e.g. vegetable gardens) rather than returned to the point of origin.

Much of the natural grazing in the tropics is on lands regarded as marginal or incapable of arable production. They usually produce a large amount of vegetation, after rain, but the crude protein (CP) content of the vegetation falls rapidly (within days) and the fibre fraction increases as soon as the rains cease (Elliott and Folkersten 1961).

Nearly 80% of the domestic ruminants of Africa are to be found in the sub-humid, semi-arid or arid zones. The high forage potential areas of tropical Africa are those where the tsetse fly, and hence trypanosomiasis, is common. Trypanotolerant breeds are therefore essential. Ruminants and other herbivores can use this vegetation to the benefit of human.

Indigenous cattle in most tropical countries are zebu (*Bos indicus*). Exotic dairy cattle have been kept successfully in large commercial herds, but are less common in the smallholder sector, where feed and other inputs are not available. Though adapted to tropical conditions, the potential of *B. indicus* for milk yield is low (Syrstad 1987, 1996). Milking operation is complicated because many of the breeds in this group do not let their milk down in the absence of the calf (Margerison 1996). Crossbreeding of *B. taurus* and *B. indicus* breeds gives an F_1 with greater potential for milk yield than either of the parents. However, because of loss of heterozygosity in the F_2, criss-crossing or establishing a composite breed are recommended (Syrstad 1987).

In contrast, Maule (1993) recommended selection within suitable *B. indicus* breeds for milk production. Over the last 30 years crossbreeding of buffaloes has resulted in a steady improvement in milk yield (Govitrika et al. 1991). There is also evidence of similar increases in milk yield in crossbred goats (Montaldo et al. 1997). Typical milk yields obtained on farm for all three species are being shown in Table 5.

The figures (Tables 5 and 6) highlight the twin problems of most smallholder dairy enterprises, i.e. low milk yield and long calving intervals. The major underlying cause is undernutrition, the result of inadequate amounts of feed, particularly in the dry season (in many instances no milk is produced at this time), which is often not fed to optimise the nutrients available.

The common feeds will be natural grazing or planted forage in the wet seasons and natural grazing, if available, and crop residues in the dry seasons. Conserving forage, either as hay, silage (Mhere, personal communication) or in fodder banks (Otsyina et al. 1987; Mani et al. 1993), is growing in importance, especially in the peri-urban sector responsible for year-round milk supplies to urban areas.

Table 5. *Milk production in buffalo, cattle and goat maintained in different governments institutes.*

Breed and country	Farm/research station	Calving interval (days)	Lactation length (days)	Lactation yield (kg)	Feed	Notes
Egyptian buffalo Egypt[1]	Alexandria University	508	311	2028	Berseem + concentrate mix	
Friesian–Bunaji Nigeria[2]	Ahmadu Bello University			2000 2058 2045	Guinea-savannah pasture + concentrate supplements	Peak rains Post-rains Pre-rains
Crossbred zebu × Holstein Mexico[3]	Centre for Research Veracruz	413 382	262 262	1376 1830	Molasses and 3% urea supplement	1st lactation 2nd lactation
English Jersey Uganda[4]	Nakyesasa Livestock Husbandry Experimental Unit	448 468	358 299	1732 (305 days) 2304 (305 days)	Pastures + mineral supplements + concentrates (61.7% starch and 12.5% protein)	1st lactation 2nd lactation
White Fulani	Shika Agricultural Research Station	370 359	220 258 286	1059 1063 1087	Savannah or Mucuna/Digitaria pasture, silage *ad libitum* with concentrates (guinea corn/ maize and groundnut cake/soybean	1st lactation 2nd lactation 3rd lactation
Sokoto Gudali Nigeria[5]		373 358	229 272 298	922 1141 1368		1st lactation 2nd lactation 3rd lactation
Butana cattle Sudan[6]	Government Dairy Farm	416	253	1421		
East African Zebu Kenya[7]	Livestock Improvement Centres	362	239	814	Pastures supplemented with brewers grains, pyrethrum residues, kibbled maize and cottonseed cake	
Northern Sudan Zebu Sudan[8]	University of Khartoum	428	294	2088 (305 days)	Green lucerne, dura + concentrate (cottonseed cake, wheat bran and lucerne hay)	
Nganda cattle Uganda[9]	Livestock Experimental Station	420	267	1033	Pasture, silage, sweet potatoes	
Sahiwal cattle Kenya[10]	Livestock Improvement Centres	388	283	334		
Sahel						
Red Sokoto		276	80	25–40		
W. African Dwarf		260	70	22–30		
Nigeria[11]		240	98	32–36		

1. Alim (1978), 2. Alhassan et al. (1985), 3. Fernanadez-Baca et al. (1986), 4. Phipps (1973), 5. Johnson and Buvanendran (1984), 6. Alim (1961), 7. Galukande and Mahadevan (1962), 8. Osman and El Amin (1971), 9. Mahadevan and Marples (1961), 10. Mahadevanand Galukande (1962), 11. Egwu et al. (1995).

Table 6. *Typical composition of milk of the major ruminant species of the developing world.*

Breed and country	Milk yield (kg/day)	Total solids (%)	Fat (%)	Protein (%)	Solids non-fat (%)	Ash (%)	Lactose %
Boer, S. Africa[a]		15.71	5.65	3.05	10.06	0.89	6.12
Red Sokoto, Nigeria[a]		15.85	5.32	4.74	10.53	0.78	4.77
Anglo Nubian, West Indies[a]		12.2	4.1	3.31	8.1	0.79	4.1
Saanen, Nigeria[a]		12.25	3.34	3.04	8.91	0.75	4.56
Swiss Saanen[b]	3.5	11.5	2.81	2.17			3.5
African Dwarf[b]	2.09	18.7	6.9	3.91			6.3
Black Bedouin[b]	1.99	14.53	3.68	2.79			3.74
Indian, Nigerian and South African goat[a]		13.9	4.8	3.7	9.1	0.85	5.0
Damascus goat[d]		13.21	4.26	4.09		0.83	
Murraha buffalo		18.7	6.5	3.7	9.7	0.86	4.8
Indian buffalo[a]		13.5	4.8	2.8	8.1	0.74	4.6
Egyptian buffalo[c]	2028 (total)	15.66	6.57 (butterfat)		9.44		
Chios ewes[d]		16.22	4.92	5.77		0.94	
Friesian cows[d]		11.2	3.28	3.13		0.74	
Friesian, Uyole[e]	6.87	12.5	3.71	3.16	8.8	0.75	
Sahiwal, Pakistan[f]		14.25	4.76	3.76	9.5	0.61	5.12
Somali camel[g]		12.5	4.0		8.5		
Turkana camel[g]		13.5	4.7		8.9		

Sources: a. Devendra (1980), b. Shkolnik et al. (1980), c. Alim (1978), d. Hadjipanayiotou (1995), e. Kifaro and Syrstad (1996), f. Hasnain and Karam (1985), g. Simpkin et al. (1998).

In extensive and semi-extensive systems, natural rangeland is a major feed resource (Gambiza 1996). Communal grazing is normal and it is managed as a common property resource (see Behnke and Schoones 1993; Wolmer 1997). Estimating carrying capacity, if calculated on plant availability, should allow a plant use of 30–50% (de Leeuw and Toothill 1993). A major variable in the system is rainfall, which affects rangeland productivity and the supply of other feed resources. Gammon (1984) listed the important principles of rangeland management as: stocking rate, rest, frequency of grazing, top hamper and litter cover. In communal rangelands, because of high stocking rates, few rest periods and frequent close grazing; top hamper (and the need for fire, either random or as a management tool) is unlikely to be a problem. Adequate water points (Gammon 1984) are rarely available.

Trees are an important component of the rangelands and have major roles such as: environmental conservation (Atta-Krah 1989); a source of fuel wood and building materials (their removal, to the extent of dung being used for fuel, is seen as an indicator of desertification) (UNESCO 1996); feed for browsers (Atta-Krah 1989) (the result of this is that a combination of grazers and browsers should increase the carrying capacity of rangeland). In semi-arid areas, the value of tree litter to cattle should not be underestimated (Smith et al. 1995a), and as a source of shade.

In most of the systems under consideration, dairying cannot be viewed in isolation from other farm activities, the most important of which is producing the staple food of the household. In the developing world 82% of total draft power comes from livestock and in the past decade the number of cattle and buffaloes used for multiple production purposes, including draft power, has increased by 23% (FAO 1992b). Studies in Ethiopia (Zerbini et al. 1993, 1995, 1996a and b) have shown that lactating cattle, including crosses of *B. taurus* with *B. indicus,* can be used for work although longer calving intervals can be expected. Thus there is an indication that the higher energy demand of work, lactation and reproduction are not met given the poor feeding systems. A similar result in a harsher environment was noted when a *B. indicus* breed was used in Zimbabwe (Prasaad et al. 1995). Pearson (1991a) reported that in Zimbabwe Jersey crossbred steers were used for draft purposes, an important by-product of the dairy sector. A dual purpose, milk and draft breed, was recommended for India, based on Holstein–Friesians and indigenous cattle (Arora and Garg 1995).

A survey in two areas of Sri Lanka found that 95% of buffalo owners were full-time crop and livestock farmers. Milk was regarded as a by-product and all buffaloes were expected to work (Goonewardene and Thevamanoharan 1994). The correct nutrition of these dual-purpose animals will be critical if both objectives are to be achieved.

In spite of the problems facing livestock production, Qureshi (1996) rated livestock as the fastest growing agricultural sector. The purpose of this review is to identify nutrition orientated research needed for the smallholder dairy subsector. While lack of feed is the largest constraint, in most situations increasing the land area available for feed production is not an option. However, more efficient production techniques such as: improved crop varieties (including quality and amount of residues where applicable, Reed et al. 1988); better and increased use of fertiliser and manure; improved water harvesting and conservation methods; improved handling and storage of harvested crops; a greater use of conservation and full use of all suitable by-products would increase the possibilities for the nutritionist to design effective feed packages.

Relevance of milk to human nutrition

The interest in smallholder milk production throughout the developing world indicates its popularity as a food, either as raw milk or after processing. While this demonstrates a role as an alternative food it does not confirm necessity for inclusion in the diet. However, many researchers (e.g. Walker 1990; Razarfindrakoto et al. 1993; Brewster et al. 1997) highlighted the problem of protein–energy malnutrition (PEM) in young children, especially for those of weaning age. Walker (1990) suggested that the greatest need of children in this age group is an adequate energy intake.

In their report of a rural project in Kenya, van Steenberg et al. (1978) found that intake of cows' milk in children was between 120 and 140 g/day from 0 to 36 months of age (lower between 13 and 18 months). This is approximately twice the current per capita consumption in Africa (Table 1). Intakes of other food (maize, tubers, legumes, vegetables, fruits, fat and sugar) increased from seven months of age. In the lower age groups, fat contributed ±48% of dietary energy, while falling to around 12% in the older age groups, who obtained most of their energy from carbohydrates. In general, children of this study area were rated as having a reasonably high nutritional status.

Two major manifestations of PEM in young children are kwashiorkor and marasmus (Walker 1990). Brewster et al. (1997) compared two treatment regimes, one based on milk and the other on cereal diet. The milk-based diet was judged superior in that it reduced mortalities and clinical sepsis and increased weight gain, and intestinal permeability.

Razafindrakoto et al. (1993) stressed the huge burden placed on health care facilities in treating PEM. Cow's milk fortified with oil and sugar is a commonly used method of treatment but it is accepted that in much of the tropics it is either too expensive or unavailable. In Madagascar, goats' milk (similar composition) has been compared with cows' milk in these diets. Daily milk intake and growth rates were similar for both sources, suggesting that goats' milk could be used to replace cows' milk. It was also suggested for inclusion in the normal diet of children. Hachelaf et al. (1993) concluded that cows' and goats' milk were similar in nutritive value but children digested the fat of goats' milk to a greater extent, which is also easier to obtain.

There is clearly a role for milk in the diet of children to combat PEM. It is likely that with increasing life spans and inadequate dental facilities in place, it may also be shown to have a role in the diets of the elderly.

Environmental considerations

Sustainability, desertification and erosion

Inappropriate livestock management may contribute to the increasing desertification and erosion of tropical agriculture under various conditions:

- an indirect but high contribution to erosion frequently followed by desertification seems to be the result of the increasing demand of western livestock populations for imported protein like soybean meal and
- a direct effect by the way of erosion caused by too intensive livestock densities (e.g. tread damages) and non-sustainable crop–livestock systems (e.g. soils not covered by crops during the rainy season).

If a semi-intensive pasturing system is established, livestock may even successfully maintain the natural resource base. This requires a shift from pure cash-crop systems to mixed crop–pasture systems with livestock providing part of the food chain. In some regions with pure crop production, livestock is constantly underfed since no pasture areas are available for grazing. In the rainy season they graze the roadsides, in the dry season they graze on crop residues. The problem is not only the poor feed quality but also limited amount of feed of any kind. An example of this scenario is goat production in western Cameroon (A. Teguai, personal communication). Establishing a minimum amount of pastures may alleviate undernutrition and also reduce soil erosion. This might help to cope with undernutrition in livestock and, subsequently, even in humans. Developing community kraals, based on zero-grazing, has been proposed to cope with land pressure in peri-urban production systems in South Africa (de Waal 1996). However, sustainable tropical crop/pasture–livestock systems have only been established at some sites and data on the particular conditions for acceptance and long-term sustainability are not yet available.

Anti-nutritional factors in animal feeds

A variety of substances are found in animal feeds, which have an adverse effect on the nutrition and metabolism of the animal. They are described as anti-nutritional and may cause undernutrition through interference with intake or important metabolic pathways. The following is a list of known and important anti-nutritional factors and examples of their source:

Alkaloids – lupin seed and forage, potatoes (green skins)
Ammonia – urea (by conversion)
Cyanogenetic glycosides – cassava tubers and linseed
Furanocoumarins – *Gliricidea sepium*
Goitrogens – brassica xrops
Gossypol – rapeseed meal
Lectins – soybeans
Mimosine – *Leucaena leucocephala*
Nitrates – maize forage, oat hay and well water
Oxalates – *Cenchrus ciliaris*, tops of roots
Proanthocyanidins (condensed tannins) – fodder trees, sorghum, cassava leaves
Phyto-oestrogens – Lucerne, clovers
S-methylcysteine – *Bracharia decumbens*
Trypsin inhibitors – sweet potatoes, soybeans

The presence of secondary plant compounds such as hydrolysable and condensed tannins that can depress feed intake and protein use constrained feed quality of legume forages and multipurpose fodder trees. There are a large number of individual compounds in plants that are called tannins (Mueller-Harvey and McAllan 1992). Whether or not they are detrimental depends on their chemical composition, the concentration in the plant and the quantity consumed by the animal (Mueller-Harvey 1999). Kumar and D’Mello (1995) reviewed the presence of these factors in tropical fodder plants.

Reed (1986) and Mueller-Harvey and McAllan (1992) reported the detrimental effects of large quantities of condensed tannins in the diet of the grazing animal. Beneficial effects of these compounds at low levels are also noted. Mueller-Harvey (1999) emphasised the molecular variability within the tannin group, terming some as ‘constitutive’ and others being present in response to outside stressors (e.g. defoliation, low soil fertility, water deficit, high ambient temperature). This list suggests that occurrence will vary with grazing pressure and between seasons, also possibly within a grazing system depending on distance from the night-pens.

Mueller-Harvey and McAllan (1992) described tannins as either condensed or hydrolysable, both often found in the same plant. The complexity of the tannin molecule and the number of variations, which exist in plants, has resulted in only a small number being adequately described (Mueller-Harvey and McAllan 1992). This, coupled with the factors already mentioned which affect concentration, make predictability of response to grazing and browsing unimproved tropical rangelands extremely difficult.

In nutrition, the problem with tannins arises from their ability to bind with protein, thus lowering the nutritive value of the plant that a chemical analysis may suggest (Reed 1986). Tannins have been considered as agents to reduce the solubility of protein, a beneficial response to a reduced concentration of condensed tannins in forages, when polyethylene glycol (PEG) was added to the diet (Waghorn 1990). The response to PEG was greater with a higher (2.2 vs. 5.5%) concentration of condensed tannins. Responses to PEG and polyvinylpyrrolidone (PVP) are variable when fed to livestock eating diets containing tanniniferous plants (Smith et al. 1995a).

Several approaches to alleviating the adverse effects of anti-nutritional factors have been proposed, and include modifying the plant (Kumar 1992) and metabolic or ruminal detoxification by the animal. Research at ILRI aimed at alleviating the effects of anti-nutritional factors has focused on rumen microbial adaptation and detoxification. Microbial strategy involves isolating and identifying naturally occurring microbes (or consortia) that possess the ability to tolerate or degrade the anti-nutritional factors, and the transfer of these microbes into the rumen of non-adapted animals for protection against the anti-nutritional factor. Previous studies (Allison et al. 1990; Osawa 1990; Brooker et al. 1994; Nelson et al. 1995; Odenyo et al. 2001; Eden 2002) have shown that bacteria capable of degrading or tolerating tannins can be isolated from animals previously exposed to tanniferous feeds. Tannin tolerant and/or degrading bacteria such as *Streptococcus bovis, Coprococcus* sp., and *S. caprinus* (Tsai and Jones 1975; Brooker et al. 1994; Odenyo and Osuji 1998), *Selenomonas ruminantium* (Skene and Brooker 1995; Odenyo et al. 2001) and *Streptococcus gallolyticus* (Sly et al. 1997) have been successfully isolated. This is an inexpensive option for smallholder farmers. The possibility of successful detoxification by transfer of micro-organisms from adapted to non-adapted ruminants has been demonstrated in the case of mimosine detoxification from *L. leucocephala* by DHP-degrading bacteria (Jones and Megarrity 1986).

Nutrient cycling

In western countries environmental problems resulting from nutrient excess of nitrogen (N), phosphorus (P), and potassium (K) in livestock systems are common. Closing nutrient cycles is then equivalent to reducing nutrient input. The situation in third world countries is quite the opposite. Nutrient exportation due to removal of products (crop, milk, meat) and nutrient loss through emissions, leaching and erosion coupled with low use of fertiliser and purchased feeds widely exceeds input. One major reason for the low supply of N appears to be the loss of almost all urinary N, even if manure is returned to the point of origin. A higher N input from feed will usually selectively increase urinary N at almost constant amounts of faecal N (Valk 1994; Sutter and Kreuzer 1995). Tanner et al. (1995) suggested the application of specific feeding strategies to increase the fertiliser value of animal dung. Legumes might be particularly valuable in this respect due to their comparably high N content.

Methane production by ruminants

Due to increasing international concern over climate change induced by rising greenhouse gas emissions, international policy makers are searching for cost effective methods for reducing global greenhouse gas emissions, including carbon dioxide, methane and nitrous oxide. Globally, the largest source of methane is enteric fermentation from livestock, which in 1990 accounted for 23% of total anthropogenic emissions (IPCC 1995), with ruminants alone being responsible for 22%. The projected increase in ruminant livestock populations in tropical regions will further increase total methane emissions.

Methane is produced by micro-organisms in the digestive tract of ruminants, and represents a loss of digested feed energy that is unavailable to the animal for milk and/or meat production. In the tropics ruminant feeding systems are typically based on low quality forages, and are associated with higher methane emissions per unit of meat and milk production than in temperate regions. As ruminant livestock populations expand in the tropics attention should be focused on improving livestock production efficiency in an environmentally and economically sustainable manner.

Nutrition

Undernutrition or malnutrition

The working definition of undernutrition used in this review is the situation where there is a lack of feed (i.e. lower feed available than desired levels of livestock production). Undernutrition is not commonly defined in standard feeding requirement textbooks, which typically begin by defined requirements for maintenance (e.g. ARC 1980). The Concise Oxford Dictionary (Pearsall 1999) gives 'undernourished' as equalling 'undernourishment'. The same volume defines 'malnutrition' as 'a dietary condition resulting from the absence of some foods or essential elements necessary for health'; 'insufficient nutrition'. There is no mention of production but as health would suffer if the feeding level was not sufficient, this aspect can be absorbed by including 'appropriate'. The dictionary definition groups both absence (there is no mention of over supply) and insufficiency of nutrients as malnutrition, although they present different problems to the nutritionist: undernutrition suggesting shortages of the major nutrients of energy and protein; malnutrition suggesting an imbalance caused by shortages and including micro-elements of the diet. Extreme undernutrition occurs in times of severe drought when famine is also likely. Preston and Leng (1987) gave some precautionary measures to combat drought, but in reality farmers, especially smallholders, are rarely able to cope. In such circumstances survival feeding is the order of the day.

According to Oetzel (1988) developing clinical symptoms as a result of severe undernutrition was considered to be malnutrition. He argued that the symptom that results from especially protein and energy malnutrition is not difficult to recognise. In ruminants, the ruminal micro-organisms also get malnourished and recovery is often difficult and prolonged. In West African Dwarf Goats, malnutrition during pregnancy was suggested as a reason for abortion (Osagwuh and Akpokodje 1986).

For the milking cow or a fattening steer there is a range of feeding levels in which production will be affected but not the health of the animal. As a plane of nutrition falls to maintenance level, the productive and reproductive functions will cease. The livestock producer will be influenced in his/her decision on level of feeding by availability of feed, cost of feed and return for product (O'Donovan 1984).

Livestock, dependant on natural grazing in the tropics, normally have to cope with underfeeding during the dry season. Because areas around kraals are the first to be grazed out, the distances walked to find feed will increase, as may the distances to drinking water. Stall-fed animals are likely to receive progressively less of a poorer diet as the season advances.

Causes of undernutrition

Fluctuations in and low availability of feed resources

Seasonal fluctuations of food resources in the tropics follow the pattern of vegetation growth that is modified by availability of rainfall. This resulted in a seasonal pattern of wet season gain and dry season loss of live weight. Seasonal fluctuations in availability and poor quality of feeds were considered to be the main constraints on sheep production in arid regions (Guada 1989). A common cause of the problem is keeping too many animals on the limited feed resources. In a smallholder dairy project in Kenya, cows had long calving intervals due to a combination of undernutrition and the ineffectiveness of artificial insemination (AI) (Topps 1994). In communal areas of Zimbabwe, where about two-thirds of the national herd are kept, overgrazing in the wet season does not allow sufficient fodder to be carried over for the dry season (Ncube and Mpofu 1994).

Low quality of feed resources

Most grasses and tree leaves in arid environments are low in nutritive value because of high contents of lignin and relatively indigestible (compared with starch) cellulose and hemicellulose. The plants require such substances to protect themselves from high temperatures and evapotranspiration, but unfortunately they lower their nutritional content and digestibility (Mathur et al. 1991). The stage of growth, maturity of grasses and taste influence their nutritional value. Mathur et al. (1991) reported that cattle kept solely on grazing mature grass exhibited loss in body weight in the dry season. The use of some roughages is also limited by their low contents of protein and digestible energy (Ncube and Mpofu 1994), especially as the season progresses. Further problems are caused by secondary factors such as anti-nutritive or toxic constituents in the plants, which restrict acceptability of the diet (Kumar and D'Mello 1995).

Low intake of supplements

Tembani et al. (1994) observed that even when cattle were given supplements, there was no gain in body weight because of low intake. Farmers usually offer more crop residues especially maize stover than the cattle can eat which, depending on the system of feeding, can result in spoilage. Therefore, consideration should be given to the nutritive value of supplements and increasing their intake (Tembani et al. 1994). Moreover, in a review of supplementary feeding to dairy cows grazing tropical pasture, Jennings and Holmes (1985) recommended that highest responses would be obtained in the short-term where supplements are used strategically to correct periodic deficits in the supply of herbage.

Unbalanced diet

A comparative study of the value of nutrients supplied to cows in small-scale dairying in three districts of Kenya showed that there was a deficit of metabolisable energy (in supporting the desired level of output) of up to 15 MJ/day and a large deficit of effective rumen degradable protein of 235 g/day. The shortage of protein was considered to be much more critical than that of energy. Topps (1994) recommended that protein-rich ingredients needed to be incorporated into the diet as substitutes for crop residues such as maize stover. By doing this, efficiency of rumen function would be increased and hence the supply of nutrients (Preston and Leng 1987; Ørskov and Ryle 1990).

Abrupt and frequent changes in the diet

Dietary imbalance is exacerbated and rumen efficiency reduced by abrupt changes to the diet. When the availability of feed is restricted smallholder farmers often use a variety of feed resources including crop thinnings and residues, weeds, tree leaves and native grasses from their own farms, communal lands or purchased from neighbouring farmers (e.g. Romney et al. 1998). Use of these feeds is often opportunistic and driven by factors such as availability of labour and the seasonal patterns of crop management. The results of frequent and abrupt feed changes in feed offered to animals are believed to be associated with reduced efficiency of use of the feed and efficiency of milk and meat production. Purchased feeds are also not standardised in terms of the ingredients. Sanda et al. (1999) showed that the pattern of feeding similar quantities of Napier grass *(Pennisetum purpureum)* and barley straw has a significant effect on live weight change, with growing steers losing more weight (–125 g/day) when the forage offered was abruptly changed every five days compared with animals receiving the same mixture of fodder daily (8 g/day).

Physiological increases in nutrients requirements

Undernutrition may be due to physiological increases in nutrient use, e.g. during early lactation when the mammary demand for substrates depletes the body for several weeks (Chilliard et al. 1998). Early lactation creates the largest demand, but intake peaks later than yield, thus creating a negative energy balance, which can only be met from body reserves or reduced milk yield (Bines 1979). In Europe farmers often feed much higher levels of concentrate at the beginning of lactation to compensate for the higher nutrient demands. However, for dairy animals in the tropics it is common to find a low rate of concentrate being offered as farmers cannot afford to invest in high level concentrate feeding, even when the returns may be beneficial (e.g. Romney et al. 2000).

Energy expenditure increases when the animal is used for draft power. Increased use of energy by oxen for plowing is shown in Table 7 (Fall et al. 1997).

Table 7. *Live weight, draft force for plowing as a proportion of live weight (DF/M), daily net energy required for maintenance (EM) and for plowing (multiple of maintenance) sandy soils for each ox in the pair, one walking on the plowed soil (A) and the other walking on the unplowed soil (B).*

Live weight (kg)	DF/M	Daily EM (MJ)	Plowing time (hrs/day)											
			1		2		3		4		5		6	
			A	B	A	B	A	B	A	B	A	B	A	B
300	0.16	34.75	0.15	0.13	0.29	0.25	0.44	0.38	0.59	0.5	0.74	0.63	0.89	0.75
400	0.12	43.12	0.14	0.12	0.28	0.23	0.43	0.35	0.57	0.47	0.7	0.59	0.84	0.7
500	0.1	50.99	0.12	0.1	0.24	0.19	0.36	0.3	0.48	0.4	0.6	0.5	0.72	0.59

Source: Fall et al. (1997).

Specific nutrients affecting undernutrition

Energy

Opinions are divided on energy metabolism and efficiency of use of energy for maintenance following a period of undernutrition. Ortigues and Vermorel (1996) reported that underfed adult non-pregnant, non-lactating ewes did not show any adaptation of their energy metabolism during a seven week period of undernutrition. The maintenance requirements for metabolisable energy (ME_m) and the efficiency with which the ME is used remained stable with duration of undernutrition. Although some behavioural adaptation occurred, it did not change the ME requirements (Ortigues and Vermorel 1996). They also found that heat production decreased rapidly within the first week of undernutrition and more or less stabilised two weeks after the change in intake. In contrast, Margan and Graham (1988) reported a 7% increase in energy metabolism during undernutrition, which they cannot explain. They also quoted work by Graham et al. (1974) in which they found a 3.5% decrease in energy metabolism during undernutrition. Another opinion is that when energy intake falls below maintenance, efficiency of use of energy for maintenance is decreased partly due to a fall in digestibility as amount of diet offered increases (ARC 1980). In their review, Chilliard et al. (1995) observed that the negative relationship between intake and digestibility is not always observed for intakes below that required for maintenance. The longer the period of maintenance or sub-maintenance feeding, the lower the efficiency of use of energy for production (product/input). Grimaud et al. (1998) showed that undernutrition (below maintenance) for three weeks resulted in lower digestibility. However, apparent digestibility increased as the period of undernutrition was extended to eight weeks. Foot and Tulloh (1977) found that digestibility was little affected by restricting intake.

It is clear that further research is required to rectify the contrasting opinions on the effect of severe undernutrition on energy metabolism. It is an important aspect for smallholder livestock production because as Margan and Graham (1988) pointed out, efficient rationing of livestock for mere survival is an economic necessity in many regions.

During periods of exogenous undernutrition, ruminants should in general be provided with at least a third of their maintenance energy requirement, otherwise lean tissue would excessively be used to provide glucose precursors. This requirement is no doubt elevated during the latter part of pregnancy and even more in lactation (Ørskov 1998). The maintenance energy requirements of non-lactating, non-pregnant beef cows was not significantly affected by body condition (Ortigues et al. 1993) which was 516 and 536 kJ ME/kg$^{0.75}$ per day for lean and fat cows, respectively. According to Walker (1993), nutrition is usually used in the priority of maintenance, then pregnancy, foetus, lactation, growth and body stores.

In two separate experiments on West African Dwarf Goats, ME requirements for maintenance were similar. Onwuka and Akinsoyinu (1989) reported 97.6 kcal (408 kJ)/kg$^{0.75}$ per day, and Zemmelink et al. (1991) reported 91.43 kcal (382 kJ)/kg$^{0.75}$ per day. The latter also reported that there was a linear relationship between intake of digestible organic matter and live weight gain. However, ME requirements for maintenance of Kenyan goats had a greater value of 132.38 kcal/kg per day (556 kJ/kg$^{0.75}$ per day) (Abate 1989) although they were in the same weight category as the West African Dwarf Goats (11–21 kg). Confined indigenous goats in Zimbabwe, aged 8–12 months and in the weight range of 10–20 kg, had a calculated energy requirement of 465 kJ ME/kg$^{0.75}$ for maintenance and 26.1 kJ ME/g for growth (Hatendi et al. 1990). The difference could be due to the effect of genetic potential or to the amount of activity. Suggested increases in energy required for maintenance range from 0% for stall-fed up to 75% for arid rangeland browsers (NRC 1981).

The requirements for maintenance given above (average 463 kJ ME/kg$^{0.75}$) are slightly higher than the mean of 17 estimates (438 kJ ME/kg$^{0.75}$, ranging from 365–530) (AFRC 1998). AFRC (1998) also suggested a fasting metabolism rate of 315 kJ ME/kg$^{0.75}$.

Protein

There seems to be uncertainty about the efficiency with which absorbed amino-acids are used by the animal, illustrated by a wide range of values (0.5–0.8) used in various protein systems (Alderman 1987). Maximum efficiency is likely to occur when protein is the first limiting nutrient, provided that the relative amounts of amino-acids in the pool available for metabolism correspond closely with the quantities that are required concurrently by the tissues (CSIRO 1990).

ARC (1984), NRC (1985) and AFRC (1993) recommended the minimum requirement of protein for maintenance for the tropics. However, there is some concern of their applicability mainly because the data used to develop the recommendations is derived mainly from animals that are adapted to a different environment than the ones found in the tropics. From a limited data set, Krishna et al. (1977) recommended that the digestible crude protein requirements for maintenance in dry cows could be reduced by as much as 30% compared with recommendations given above. In Europe, evaluation based on digestible crude protein has been widely replaced by more sophisticated systems, such as the metabolisable protein (AFRC 1993), which consider the protein flow to the duodenum. It seems, however, that these systems bear great uncertainties for extreme low protein–low energy rations like common tropical feeds. This indicates a demand for experimental data in this field to be able to develop specific recommendations for the tropics.

There seems to be scarcity of information in the literature on the minimum maintenance requirement of protein for goats. The digestible crude protein (DCP) requirement for maintenance of Cameroonian Dwarf Goats was calculated to be 1.09 and 1.56 $g/kg^{0.75}$ per day for animals given groundnut cake and unextracted soybean meal, respectively, and 8.18 and 10.21 $g/kg^{0.75}$ per day for growth (Reuben 1992). In a similar trial, Onwuka and Akinsoyinu (1989) calculated the DCP requirement for maintenance of West African Dwarf Goats fed cassava leaves with peels as a supplement to be 0.55 $g/kg^{0.75}$ per day. Comparisons of protein requirements were also made between the DCP and metabolisable protein (MP) (AFRC 1993, 1998), and between breeds indigenous to the tropics and those to the temperate regions.

In animals losing weight, catabolism of body tissues releases amino-acids into the bloodstream. However, CSIRO (1990) reported that neither the British system (ARC 1980, 1984; AFRC 1993) nor the American system (NRC 1985) gives consideration to the consequences of live weight losses during periods of undernutrition, which are important episodes in animal systems in parts of Australia and of course smallholder farming systems in the tropics.

Animals can use fat depots, not only to support pregnancy and lactation but also to support growth if they get sufficient dietary protein. Ørskov (1998) stated that it is possible to have a fat animal maintaining weight and even increasing in weight during a considerable period of exogenous undernutrition provided it is supplied with sufficient protein of the kind that escapes degradation of the rumen. In contrast, the supply of metabolisable protein from rumen microbes is also reduced when high-fibre diets low in rumen-degradable protein are offered. In this situation, fibre digestion will be suppressed because the minimum N requirements of the microbes are not met (Owens and Bergen 1983).

Requirements for protein supplementation should be specified as precisely as possible because protein feeds are generally the most expensive components of livestock rations (CSIRO 1990). However, fluctuations in world commodity prices affect the cost of protein supplement. Smith et al. (1995b) recommended that partially replacing true protein with urea would probably be feasible with relatively short feeding intervals and the source and amount of non-protein-nitrogen and its associative effects with specific background feed need further study.

Protein supplementation increased dry matter intake substantially in animals fed a basal diet of low-quality hay compared with unsupplemented or crop residue supplemented animals (Hennessy et al. 1983; Huston et al. 1988). A greater synthesis of glucose due to increased availability of amino-acids lead to substantial increases in live weight gain in animals supplemented with 600–1200 g protein meal pellets per day (Hennessy et al. 1983). In this situation protein is used as a source for glucogenic precursors, which can lead to excessive N-excretion in urine. Although pasture is not deficient in CP during the wet season, some amino-acids may be limiting and their supplementation to increase intestinal protein supply could increase live weight gain by up to 300 g/d (Poppi and McLennan 1995).

Protein–energy balance

Live weight gain depends mainly on the supply of amino-acids and energy-yielding substrates. Depositing protein depends on the efficiency of use of absorbed protein, which is dependent on the availability of non-protein energy-yielding substrates (Poppi and McLennan 1995).

In tropical pastures, legumes are being promoted as a main source of protein. However, Poppi and McLennan (1995) concluded that although legumes increase protein intake, they generally do not increase intestinal protein supply per unit of dry matter intake. They speculated that improved animal performance due to legumes is probably because they are known to promote higher intakes. Further research is required to investigate protein–energy balance of legume-supplemented diets. The potential of legumes to increase intestinal protein supply by decreasing its loss in the rumen probably using energy supplements, thereby improving ruminal N utilisation should be investigated as well. For example, Poppi and McLennan (1995) calculated a theoretical increase in intestinal protein supply of about 25 g/kg of OM intake when signal grass and leucaena are mixed at a ratio of 70:30. van Vuuren et al. (1992) showed an almost linear increase in duodenal Non Ammonia Nitrogen (NAN) flow as the N intake increased in cows fed 15 kg/day of OM. However, intestinal protein supply per unit of N intake was related negatively to the N:OM ratio of the diet.

Chowdhury and Ørskov (1997) challenged the commonly held view that the output from protein depends on the level of energy supplied and vice versa. They produced evidence that during energy undernutrition, increasing the protein supply increased N retention curvilinearly. Increase in tissue gain was more closely related to protein availability at the intestinal level because endogenous fat can serve as a source of energy to fuel protein accretion. In a previous study, Chowdhury et al. (1995) reported that during energy undernutrition in sheep, infusion of volatile fatty acids improved N retention. Implication of the above results is that if the objective is to sell the animals during the dry season, then it is conceivable to supply the animals with the appropriate protein and keep constant body weight. However, in most smallholder farming systems the animals are allowed to graze in the rainy season in which case the animal can compensate rapidly and protein supplementation during the dry season makes it uneconomical. Protein supplementation during the rainy season can, however, increase the rate of repletion and compensation with cattle gaining up to 2–3 kg/day and lambs 500–700 g/day (Ørskov and Hovell 1986). We also suggest that in places with seasonal fluctuation of food availability, it is better to select animals that can gain fat easily so that they can use it as source of energy during periods of undernutrition.

Krishna et al. (1977) queried if the requirements of energy and protein of Indian dairy animals are similar during winter and summer seasons (differences may arise due to increased heat production in winter). They also cited conflicting references regarding the requirement of energy and protein for maintenance in lactating cows and recommended more research to estimate the differences between basal metabolic rates in cows during lactation and dry period in India.

Minerals and vitamins

Mineral deficiencies or imbalances in soils and forages have long been held responsible for low production and reproduction problems among grazing cattle in the tropics and their supplementation can increase calving percentage by 20–100% and growth rates by 10–25% and reduce mortality significantly (McDowell et al. 1984a).

Minerals essential for ruminants include macro minerals such as: calcium, phosphorus, magnesium, sodium, potassium, chlorine and sulphur, and trace minerals such as: copper, molybdenum, iron, manganese, zinc, selenium, cobalt and iodine (McDowell et al. 1984a). Maintaining optimum rumen fermentation with straw-based rations requires a minimum mineral supply as given by Moss et al. (1994).

Calcium (Ca) and phosphorus (P)

Although P deficiency is indisputable, there seem to be conflicting reports on availability of Ca in tropical grasses. For example, Jumba et al. (1996a) in a survey of the macro-mineral concentrations in herbage in Western Kenya reported that 73% of the sampled forages would not meet the Ca requirement for maintenance of cattle and sheep. However, Youssef and Braithwaite (1987) and Minson (1990) reported that most tropical grasses would satisfy the requirements of cattle and sheep. As acknowledged by Jumba et al. (1996a), the stage of growth of grasses at which the analysis was done could have affected the discrepancies observed in Ca concentrations.

The most common mineral deficiency in the world is that of P (McDowell 1984a). Phosphorus concentration in tropical grasses (Table 8) and forage legumes (Harricharan et al. 1988) is extremely low. Furthermore, concentrating P is variable depending on the season (Minson 1990; Jumba et al. 1996a). Lower P concentrations are, therefore, observed in the summer probably due to higher light intensity and temperature. Seasonal variability in P requirements is also predicted. Body P decreased during the growing season due to high live weight gain and was static or increased during the dry season (McCaskill 1990).

Table 8. *Mineral concentration of tropical grasses of Kenya, Trinidad and all tropical grasses.*

	Percentage of grasses with mineral concentration less than shown for each element			Recommended requirements in g/kg DM except for Cu, Fe, Mn and Zn which are given in mg/kg DM			
Element	Kenya	Trinidad	General	Beef[a]	Dairy[b]	Sheep[c]	Lactating ewe[d]
Ca		<3 g/kg DM		2.6	2.5	2.2	2.5
	15	0.9	12.5				
P		<2 g/kg DM		2	2.47	1.4	2.3
	80	71.7	42				
Na		<1 g/kg DM		0.5	0.8	1.1	1.2
	41.5	30.0	–				
Mg		<2 g/kg DM		1.2	1.4	0.9	1.2
	66	41.5	25				
Cu		<10 mg/kg DM		7.6	11.7	7.4	9.6
	98	98.1	75				
Fe		<100 mg/kg DM		30.0	40.0	30.0	–
	12	0.9	–				
Mn		<100 mg/kg DM		30.0	40.0	30.0	–
	6	1.9	–				
Zn		<30 mg/kg DM		25.0	25.0	30.0	48.0
	36	52.8	–				

a. Beef for a 500 kg gaining 0.5 kg live weight per day.
b. Dairy for a 500 kg giving 10 kg milk per day.
c. Sheep for 40 kg lamb gaining 0.1 kg live weight per day.
d. Lactating ewe for 40 kg lamb giving 1 kg milk per day.
Data on Kenya taken from Jumba et al. (1996a, b), on Trimidad from Youssef and Braithwaite (1987), and tropical grasses in general from Minson (1990).
Recommended requirements of Ca, P, Na and Mg taken from Minson (1990) and ARC (1980

Phosphorus deficiency in Bolivia was found to have an effect on reproduction such that the difference in pregnancy rate between P supplemented and salt supplemented was more than 10% (McDowell et al. 1984b). High-yielding dairy cows, which received only 70% of the estimated P requirement, showed a drop in milk production after 100 days (H. Valk, personal communication). In Western Kenya, supplementing 3.6, 3.4 and 5.2 g/day of Ca, P and Na, respectively, were estimated to meet requirements for lactating goats and 1.9 and 1 g/day of P and Na, respectively, for growing goats (Musalia et al. 1989). Similarly, a survey of macro-mineral status of sheep in Colombia revealed that animals needed to be supplemented with Ca, P, Na and Mg (Pastrana et al. 1991a). Phosphorus supplement requirements were predicted to be higher in pregnant and lactating cows when compared with the current recommended amount in northern Australia (McCaskill 1990).

Characteristic symptoms of Ca deficiency include stunted growth, impaired or unnatural appetite, distorted spine, ribs and tubular bones, unsteady walk and lameness (Georgievskii 1982a).

Absorbing P is related to retaining Ca. Deficiency of either one of the minerals makes the use of the other mineral less efficient (Minson 1990). Therefore, not only are both minerals important on their own but the ratio of Ca to P must also be maintained for better animal performance (a ratio of 1:1 or 1:2 must be achieved, McDowell et al. 1984a).

Magnesium (Mg), sodium (Na), potassium (K) and chlorine (Ch)

Magnesium is required for many energy-transfer reactions within the body and voluntary food intake of cattle and sheep is depressed by Mg deficient diet (Minson 1990). The Mg in tropical forage was not considered to be limiting (Youssef and Braithwaite 1987; Minson 1990; Schillhorn van Veen and Loeffler 1990) although Jumba et al. (1996a) reported exceptionally low Mg concentrations in Kenya (Table 8).

Animals showing clinical symptoms of Mg insufficiency produce more heat, which is accompanied by a poorer use of the feed energy. Hypomagnesaemia in adult ruminants, known as grass or pasture tentany, does not seem to be a typical manifestation of Mg deficiency, even though it can be prevented or cured by administering Mg salts (Georgievskii 1982a).

Absorbing Mg is reduced by low ratio of sodium to potassium (Minson 1990). There is conflicting evidence of availability of K in the tropics. McDowell et al. (1984a) claimed that K deficiencies are unlikely in most ruminal diets and Schillhorn van Veen and Loeffler (1990) indicated normal K levels in non-nomadic cattle in Nigeria. Youssef and Braithwaite (1987) found that most of the 106 tropical grasses analysed would not satisfy the requirements of sheep and cattle. Symptoms of K deficiency include impaired growth and appetite, bristling hair, ataxia, atony of the intestine and impairment of cardiac activity. Excess K is toxic to calves (Georgievskii 1982a).

There seem to be a general agreement that Na is deficient in most tropical grasses, which can be corrected by providing common salt *ad libitum* which also satisfies the requirement for chloride (McDowell 1985a). Cattle deprived of salt may be so voracious that they often injure each other in attempting to reach salt. Lactating animals suffer most from lack of salt in the diet due to high levels of NaCl secreted in milk (McDowell et al. 1984a).

Copper (Cu) and molybdenum (Mo)

According to McDowell (1985a), copper deficiency in tropical countries is second only to P. According to Youssef and Braithwaite (1987) only 9% of tropical grasses satisfied the Cu requirement for cattle in Trinidad and Tejada et al. (1987) reported that 94–100% of cows in Guatemala were deficient in Cu. In Africa, Cu deficiency is common in the Rift Valley that stretch from Ethiopia to Tanzania, and in Kenya, Zaire, Malawi, Sudan and Nigeria (Schillhorn van Veen and Loeffler 1990). In addition, Cu has a low percentage release in the rumen, which increases the problem of Cu deficiency (Kabaija and Smith 1988).

Symptoms of Cu deficiency include anaemia, impaired growth and development, diarrhoea, depigmented hair and wool. Copper deficiencies can be prevented by supplying Cu as a feed supplement dosing or drenching the animal at intervals or by injecting organic complexes of Cu (Minson 1990).

Although Molybdenum is essential for animal health, intake of Mo can cause large reductions in Cu absorption (Chesworth 1992). Cases of Mo deficiency in farm animals have never been recorded in practical conditions but excess Mo has adverse effect on digestive and metabolic processes in ruminants (Georgievskii 1982b).

Iron (Fe) and manganese (Mn)

Youssef and Braithwaite's (1987) chemical analysis supported the claim by McDowell et al. (1984a) that most of tropical soils are acidic, resulting in forage levels of iron and manganese in excess of requirements for cattle and sheep. High Mn concentrations may interfere with the metabolism of other minerals and has been observed to result in low reproductive rates of cattle (McDowell et al. 1984a). Even with a moderate and permanent excess of Fe in the diet, the liver becomes saturated with Fe, which is then deposited as colloidal iron sulphate, which is harmful (Georgievskii 1982b).

Zinc (Zn)

Zinc was deficient in 35–50% of tropical grasses (Table 8). A Zn deficiency for grazing livestock was reported to cause parakertosis skin disorder and in more acute cases rapidly spreads over about 40% of the body surface (McDowell et al. 1984a). Supplementing food with mineral mixtures containing Zn improved animal performance in many tropical countries (McDowell et al. 1984a; McDowell 1985a). Zinc supplementation was also recommended in sheep in the Paramo region of Colombia (Pastrana et al. 1991b). In Western Kenya together with Na and P, Zn deficiency was considered to be one of the limiting factors of production in goats (Musalia et al. 1989).

Selenium (Se)

There are some indications that Selenium deficiency is emerging in Africa as in the rest of the world (Schillhorn van Veen and Loeffler 1990). To support their claim, the authors quoted references to diseases caused by Se deficiency in Kenya and Zimbabwe. Se deficiency in soil and forage was also detected in Colombia although serum samples from the liver did not show such deficiency (Pastrana et al. 1991c). However, the authors found that ewes injected with Se produced 1036 kg lambs/100 ewes compared with 725 kg for controls. In grazing animals, distinct Se deficiency syndromes have been described as 'white muscle disease' in newborn or young lambs and calves. Other symptoms include ill-thrift with poor growth rates, infertility and retained placenta (McDowell et al. 1984a).

Cobalt (Co)

Cobalt deficiency has been reported in Kenya, Tanzania, Zaire and Ethiopia (Schillhorn van Veen and Loeffler 1990). Co deficiency signs are not specific, and it is often difficult to distinguish between a deficiency of Co and malnutrition due to low intake of calories and protein. However, Co-deficient cattle respond quickly to Co treatment, recovering appetite, vigour and weight (McDowell et al. 1984a). Co supplementation together with good pasture had a significant effect on live weight gain (Schillhorn van Veen and Loeffler 1990). Pastrana et al. (1991b) also recommended Co supplementation in Colombia.

The conflicting reports on mineral status of tropical feed need clarification. Studies particularly relating to deficiencies of P, Cu, Mg, Mn and Se need to be addressed. Schillhorn van Veen and Loeffler (1990) in their review of mineral deficiency in ruminants in SSA concluded that 'the present lack of data and understanding of the problem are, at least in part, a cause of the stagnation in the further improvement of the African livestock industry'.

Vitamins

In addition to energy, protein and minerals, animals must obtain a number of highly specific molecules or vitamins from their diet or from bacteria present in the digestive tract (McDowell 1985b). In his review of vitamin nutrition of cattle under tropical conditions, McDowell (1985b) stated that in practical feeding of grazing cattle, under most circumstances, vitamin deficiencies should not be a major problem. In grazing cattle, McDowell (1985b) suggested that only vitamin A and possibly vitamin E might be supplemented due to synthesis of B-vitamins (B-complex, B_6 and B_{12}), vitamin D and K in grasses.

Supplementing vitamin A in Friesian crossbred cows in Iraq significantly increased the number of cows coming into oestrus within 60 days of calving. However, no significant increases were detected in blood serum among cows supplemented with vitamin A compared with unsupplemented cows (Ghannam and Abd-Elraheem 1978).

McDowell (1985b) gave a detailed review of vitamin deficiency, minimum requirement and vitamin supplements under tropical conditions.

Water

Water is essential for all animal and plant life. Availability of water controls the supply of feed and animal performance. The animal obtains its water from three sources: drinking water, water contained in feed and metabolic water (Payne 1990). The factors affecting water in cattle include: the amount of dry matter eaten, the nature of the feed, level of salt intake, air temperature, water temperature, physiological state of the animal, availability of water and the succulence of the feed (CPA 1988). Buffaloes are only suited to wet zones whereas cattle and goats can tolerate arid and semi-arid conditions, the goat in terms of water economy and turnover rate being the best suited (Devendra 1987).

Water supply, if limited, restricts voluntary feed intake and feed utilisation of livestock depending on various factors and mechanisms (Langhans et al. 1995). ARC (1980) gave water requirements in terms of water required per kg dry matter (DM) ingested. For cattle, beyond the young calf stage, most estimates are within the range of 3–5 kg water per kg DM. For lactating cows giving 10 kg of milk per day and weighing 600 kg, an increased intake (from 78 to 105 kg per day) is predicted when the temperature rises from between –17–+10°C to 21–25°C (see Table 9).

Table 9. *Total water intake of lactating cows (kg/cow per day).*

Milk yield (kg/day)	Live weight (kg)	Environmental temperature (°C)			
		–17 – +10	11–15	16–20	21–25
10	600	78	81	92	105
	350	52	54	61	70
20	600	88	92	104	119
	350	62	65	73	84
30	600	99	103	116	133
	350	73	76	85	98
40	600	109	113	128	147
	350	88	92	104	119

Source: ARC (1980).

Cattle in the tropics will receive salt and minerals from the diet, in feedstuffs or as supplements or in the drinking water (CPA 1988). An excessive salt intake will increase the amount of water drunk (salt is often offered as an appetite stimulant or as a carrier of protein/nitrogen or mineral supplements). A safe limit of salts in drinking water is given as 1.5% (CPA 1988). Bahman et al. (1993) compared brackish well water (3574 mg total dissolved solids (tds) per litre, with desalinated water (449 mg tds per litre) for dairy cows. Milk yield was unaffected by source but the shape of the decline in lactation curve was slower with the brackish water. The authors attributed this in part to the improved mineral status of cows receiving brackish water. They thus call for more research on the possible benefits and safe upper limits of salinity in drinking water.

The effect of water temperature on intake is not clear. CPA (1988) and Payne (1990) suggested that in hot weather cattle prefer water located in shade. Olsson et al. (1997), in a short-term study, found that lactating goats drank more warm water, than cold, at high ambient temperatures. In practice, controlling the temperature of water from natural and field drinking points is difficult. ARC (1980) recommended that water should be available at all times. When the ambient temperature is not excessive (above 27°C), grazing animals like to drink every two or three hours. They normally drink in the cool of the morning or in the evening, but if herded to a watering point they will be expected to drink in the heat of the middle of the day (Payne 1990). Given free choice grazing cattle seek shade to rest at this time (Smith et al. 1995a).

Baudelaire (1972) suggested that watering at 1–3 day intervals was sufficient. With penned animals fed at maintenance, and receiving water *ad libitum*, for 2.5 hours per day, or 2.5 hours per three days, total water intake was positively correlated with DM intake and roughage concentration in the diet. Total water intake was greater in those watered daily compared with every three days (Hatendi et al. 1996). In this experiment watering pattern did not affect rumen degradability and outflow rate of low quality veld hay and apparent digestibility of dry matter (Sibanda et al. 1997).

Physiological state will affect water requirements. Lactation increases water intake and ARC (1980) suggested an extra allowance equal to the volume of milk produced. Little and Shaw (1978) found that water intake was correlated with milk yield (range 13.7–30 kg/day) and DM intake (4.6–14.4 kg/day) but not with body weight (400–620 kg) or air temperature (7–20°C). An equation was derived for water intake (kg/day): 2.15 × DM intake + 0.73 × milk yield (kg/day) + 12.3. Care should be taken in applying this equation to lactating cows in the tropics because it was developed for lactating cows in a temperate environment. With lactating dairy cows water intake strongly varies with urine production. An equation was derived that predicted urine volume from the excess minerals that need to be excreted in the urine. In practice feed intake, salt, protein content of feed and milk yield can be used to determine water intake (Bannink et al. 1999).

ARC (1980) summarised that young calves, whose digestive system is geared for a liquid diet, needed more water per kg DM intake, than older stock. The requirements of pregnant dry cows are not clear (ARC 1980), but they are likely to be higher than non-pregnant animals. Matthewman and Dijkman (1993) draw attention to the lack of information on the water requirements of draft animals and the need for research into this topic. This comment is particularly relevant because of the interest in the potential for work of the lactating animal (e.g. Prasaad et al. 1995; Zerbini et al. 1996a).

When water is limited for shorter periods dairy cattle reduce the water content of faeces but urine production tends to be unaffected, as does milk yield (Little and Shaw 1978). The goat is able to concentrate its urine and keep evaporative heat loss at a minimum, unlike the water buffalo who, well suited to the wet tropics, has low urine concentration capacity (Devendra 1987).

The water contribution from feed will vary widely, from dry feeds often containing + 900 g DM/kg through to wet season grazing. It is likely that when wet feed is being eaten total water intake will be high, but there will be some reduction in the amount drunk. In Ghana, Shorthorn heifers grazing pasture obtained 43 and 93% of their water from drinking in the wet and dry season respectively (Aggrey 1985). The reverse of this argument is that in the wet season, when grass can have a low DM content, those animals dependant on it may be underfed. DM intake may be reduced because of the bulkiness filling the rumen; and there is a limit as to how much grass a person can carry allowing for his/her other daily chores. This latter point is probably of greater relevance when there are a number of animals to feed (Massawe, personal communication).

Tolerating water stress is regarded as an adaptive trait in indigenous breeds in the tropics. Winchester and Morris (1956) and Colditz and Kellaway (1972) found lower water intakes in *B. indicus* compared with *B. taurus* cattle, the differences starting at 4°C and increasing up to 40°C.

Buffaloes are usually kept in the less arid areas of the tropics and their water requirements have not been looked at in such detail as cattle.

In goats water intake increases as ambient temperature increases (Dahlanuddin and Thwaites 1993; Abdel Samee 1996). The effects of infrequent watering on dry matter intake and rate of passage are demonstrated in Table 10 (Brosh et al. 1986), where restricted intake reduced energy intake, but increased retention time (in the rumen and whole gut) and digestibility. These changes, and similar responses noted above could be a partial cause of the low intakes recorded in tropical domestic ruminants, and conversely their ability to survive long periods at levels of feeding below maintenance.

Table 10. *Water and energy requirements and mean retention time of digesta in the gut of four black Bedouin goats fed lucerne hay and given water either once every four days or once daily (mean ± S.D.).*

	Water offered	
	Once every 4 days	Once daily
Water consumption (ml/kg$^{0.75}$ per day)	138 ± 7	247 ± 21
Gross energy intake (kJ/kg$^{0.75}$ per day)	907 ± 26	1496 ± 43
Digestible energy intake (kJ/kg$^{0.75}$ per day)	603 ± 18	938 ± 23
Mean retention time of Cr* mordanted digesta:		
in the rumen	37.8 ± 7.3	26.4 ± 3.4
in the entire gut	63.1 ± 13.0	47.3 ± 3.4

* Chromium mordant.
Source: Brosh et al. (1986).

Plane of nutrition

Production function

Growth

The efficiency with which a growing animal converts feed energy and protein into meat depends on the way in which the feed is partitioned into energy retention in the body as fat and protein and heat production. Body gain, protein and fat retention depend on the age, sex and genotype of the animal (Susmel et al. 1986). To exploit differences in genotype and to profit from heterosis effects, cross-breeding has been adopted as a strategy for improving productivity of indigenous breeds in Ethiopia but this requires improved feeding and management to exploit the full potential of the improved stock (anonymous, cited by Khalili et al. 1992). Feeding extra milk to crossbred calves decreased intake of concentrates and increased live weight gain significantly. Allowing *ad libitum* access to water associated with an increase in concentrate intake for crossbred calves did not result in significant increase in performance (Khalili et al. 1992).

A buffalo can efficiently use urea-N and wheat-straw fibre and its production can be economically sustained when fibre intake is below 29% of the dry matter intake and the total ration meets the ME requirement. However, with age and increase in size of the animal, the available energy will be limiting (Bakshi and Langar 1986).

Susmel et al. (1986) believed that few studies have been conducted to allow comparisons of the effects of genotype and nutrition without bias and this area deserves more research to identify breeds that can maximise productivity depending on their energy and protein requirements.

Pregnancy

The earliest stage of development at which nutrition influences an animal's subsequent ability to achieve its genetic potential for reproduction is still uncertain. Prenatal growth retardation caused by feeding ewes on a ration as low as 0.5 times maintenance during early pregnancy had no subsequent detrimental effect on either the natural or gonadotrophin stimulated ovulation rate of the progeny (Robinson 1990). Some live weight losses in early pregnancy were not detrimental to the offspring. Undernutrition does not permanently affect embryonic development of the primordial germ cells (Parr et al. 1986).

In ewes, undernutrition during late pregnancy resulted in a substantial loss of both maternal live weight and foetal weight (Leery et al. 1990). This is probably because the foetus normally achieves 70–80% of its birth weight during the last six weeks of a 21-week gestation (Bell et al. 1988). According to Robinson (1983) the adverse effect of undernutrition is much more pronounced when accompanied by low protein intakes. However, Bell et al. (1988) reported that a foetal intravenous infusion of glucose alone was as effective as a combined infusion of glucose and amino-acid in sustaining foetal growth in underfed ewes. Further research is required on the nutritional requirements of the dam and foetus during late pregnancy.

Undernutrition also reduced the glucose intake by uterus but net uptake was increased in exercising ewes in response to an increase in maternal glucose flux (Leery et al. 1990).

Lactation

A high rate of gluconeogenesis is ensured in dairy cows during early lactation with increased lipid mobilisation and fatty acid oxidations in the liver by regulating metabolite transport across mitochondrial membranes. However, in severely underfed animals, with excessive lipid mobilisation and ketogenesis, glucose synthesis is depressed (Danfaer 1994).

Dairy cows subjected to severe undernutrition over their first four lactations maintain large response ability when fed liberally (Coulon and Ollier 1996). Jones and Garnsworthy (1989) suggested that cows adjust their food intake according to body condition at calving provided that the energy concentration of the diet is sufficiently high. Later, Jones and Garnsworthy (1989) suggested that cows that are thin at calving are more efficient but the high-energy diets needed for milk production should contain high fibre and fat rather than high starch levels for the first 16 weeks of lactation (Garnsworthy and Jones 1993). This is because high fibre levels in concentrates enhance intakes in thin cows.

There is a remarkable interaction between the genetic potential for milk production by cattle and the balance of available nutrients for milk production, particularly in the tropics

(Leng 1990). Leng (1990) further suggested that the approach to developing diets based on the concepts of stimulating an efficient digestive system and efficient metabolism will be more appropriate than predictions on the chemical analysis of the feed or its ME content. However, Fandrejewski et al. (1998) noted that information concerning the energy and protein metabolism by lactating animals in various nutritional states is still limited.

Rapetti et al. (1998) estimated the daily ME for maintenance in lactating goats to be 484 kJ/kg $BW^{0.75}$ which is similar to values for dairy cows. However, they confirmed that the energy value of milk in high yielding goats is lower than that of cows' milk. In terms of mineral content, buffalo milk had higher levels of calcium, magnesium, sodium, phosphorus and selenium than cow milk, which was only higher in potassium (Merkel et al. 1992).

Undernutrition reduces colostrum production and in severe cases delays the onset of lactogenesis. Maternal nutrition therefore, through its effects on foetal metabolism, foetal growth and colostrum production plays a key role in neonatal viability (Robinson 1990).

Draft power

Whereas in the developed world 11% of draft power comes from animals, this figure increases to 52% in the developing world (FAO 1992b). In India, it is estimated that 90% of tillage work is carried out using draft animal power (Arora and Garg 1995). Of the recognised 26 breeds of cattle 14 are draft types. Crossbreeding with the Holstein–Freisian is envisaged to produce dual-purpose breeds to meet both the needs for milk and draft (Arora and Garg 1995). Pearson (1991a) and Nengomasha (1997) reported the role of draft power in the Jersey-based dairy crossbreeds. For many farmers, in the foreseeable future, it is unlikely that the functions of milk production and supplying draft animal power will be seen as separate.

The cow has two roles in the supply of draft animal power: as a source of draft animal power itself and as a producer of oxen. In an experiment in Ethiopia, Gemeda et al. (1995) compared the milk output and reproductive performance of crossbred (Friesian × Boran; Simmental × Boran) over three years. Half of the animals received hay alone and half hay plus a concentrate supplement. Milk production was improved by the supplement regardless of whether the cow was working or not (a small, non-significant drop in yield in working compared with non-working). Unsupplemented cows failed to conceive after 730 days and there was an indication of a tail-off in reproductive performance with working supplemented cows (Table 11). Dry matter intake was increased by both the supplemented and working. The quality of the hay used throughout this trial was higher than the roughage available for most of the year in semi-arid systems. Using similar animals and diets, Zerbini et al. (1995) again recorded increased intakes in supplemented and working animals, this being coupled with increased digestibility, for which the reasons were not clear. However, the fall in plasma glucose due to work in supplemented cows was less than the fall between supplemented and non-supplemented cows, reflecting the change in the scale of probability of conception in these groups (see also Zerbini et al. 1993).

The increased dry matter intakes and digestibilities reported above have not been found in all instances (Matthewman and Dijkman 1993). Limitations in feed quality and availability, together with reduced feeding and rumination time are suggested as possible reasons for this.

Table 11. *Lactation performance of F_1 crossbred cows over a period of three years.*

	Treatment*			
Parameters	NWNS	NWS	WNS	WS
Cumulative days in milk (days)				
0–365	291	302	280	355
0–730	501	579	476	662
0–1095		846		864
Milk yield (kg)				
0–365	849	1792	802	1770
0–730	1226	3186	927	3044
0–1095		4502		4050
Milk fat (kg)				
0–365	34.9	73.3	36.1	80.1
0–730	50.2	129.6	41.8	136.7
0–1095		172.4		175.9
Milk protein (kg)				
0–365	22.0	47.6	19.7	49.9
0–730	32.2	84.6	23.1	86.4
0–1095		114.3		113.6

NWNS = non-working non-supplemented; NWS = non-working supplemented; WNS = working non-supplemented; WS = working supplemented.

Source: Gemeda et al. (1995).

Cattle are the largest suppliers of draft animal power being widely used in Africa, Asia and Latin America. The next most important species is the water buffalo, especially in the wetter more humid areas of Asia (Pearson 1991b). Ramaswamy (1994) estimated that there are about 140 million domestic buffaloes in the world, half being in India of which 8 million are used for work. They are described as a triple purpose animal hampered by underfeeding.

Level of feeding affects metabolic rate (watts) in oxen, i.e. at a higher level the rate was similar before and after work (Lawrence et al. 1989a), while at a lower level it was 8.5% higher in a 17-hour period after work. The authors, therefore, concluded that at the lower level of feeding, the oxen had fewer reserves and, therefore, had to replace energy after work. Lawrence et al. (1989b) found that ‘resting metabolic rate’ measured at the same time each day was similar, whether or not the animal was working. However, in a 20 minute standing period after work, metabolic rate increased by 26%. Dijkman and Lawrence (1997) reported a walking energy expenditure of 1.47 J/m per kg for *B. indicus* oxen. Lawrence and Stibbards (1990) found work efficiencies (work done/work expended) of 0.30 and 0.37 for Brahman cattle and water buffalo, respectively. Collars were found to increase efficiency compared with yokes.

A comparison of well-fed (twice maintenance) draft cattle *(B. indicus)* and buffaloes in pulling carts in hot conditions found little difference in their output of work energy (Table 12) (Pearson 1989). Buffaloes took longer to complete set tasks because of their need to wallow, to reduce temperature, which was more volatile than that of cattle. Pearson et al. (1989) commented on the stress of oxen plowing at the end of the dry season in Nepal. This applies to most draft animals in semi-arid areas, their lack of condition being a constraint to timely tillage operations.

Table 12. *Live weight, load carried, distance travelled, work done and estimated net energy expended in work by two teams of buffaloes and two teams of oxen used to cart loads on the Terai in East Nepal.*

		Buffaloes		Oxen	
		Large	Small	Large	Small
Live weight (kg)	Left	464	320	551	360
	Right	401	237	557	424
	Total	865	557	1108	784
Load carried (kg)		621	380	621	587
Load: weight of team		0.72	0.68	0.56	0.75
Distance travelled (km)		16.8^{a}	16.7	16.7^{a}	16.9^{a}
Work done (kJ per team)		5590^{a}	5028^{c}	5428^{b}	5664^{a}
Work done (kJ/kg $M^{0.75)}$		35	43.8	28.3	38.3
Estimated net energy used for work (kJ/kg $M^{0.75)}$	Left	249^{b}	251^{b}	241^{c}	$261^{a, b}$
	Right	255^{b}	268^{a}	241^{c}	254^{b}
Estimated net energy used for work (expressed as a multiple of maintenance)	Left	0.76	0.75	0.74	0.78
	Right	0.77	0.79	0.74	0.77
Number		6	6	6	5

Values with the same superscripts are not significantly different ($p<0.05$).
Source: Pearson (1989)

The extra energy needed for work is approximately 1.8 times maintenance (Pearson and Dijkman 1994). However, often it is not the growing season and stored or conserved feeds are not available. Weight loss is unavoidable, although a balance between this and production is desirable. Ambient temperature, implement design, intensity of work and working conditions all contribute to the overall level of stress (Pearson and Dijkman 1994). In comparing cattle and buffaloes in muddy conditions, Dijkman and Lawrence (1997) found that the mechanical efficiency of buffaloes was greater (36.1 vs. 29.6%). However, the buffaloes were considerably heavier than the cattle.

More information is required on the nutrition of draft animals, especially those regarded as dual-purpose. The indications are that in drier areas, with less and poorer quality feed, problems will increase. Greatest output is required at the time of least availability of inputs. Two possible lines of investigation are: nutritional manipulation within the animal (e.g. energy reserves), and conserving feedstuffs for strategic supplementation.

Reproduction

Reproductive performance is highly affected with undernutrition. To ensure the sustainability of milk production, regular reproduction is necessary to induce lactation and maintain a supply of herd replacements. In a major review of the subject, Robinson (1990) outlined the effects of underfeeding on puberty through to the parturition–to–rebreeding interval. He concluded that although there was good evidence on the effects of nutrition on blood metabolites, knowledge of the trigger mechanisms, necessary to activate the various stages of the reproductive chain, were not known. Is it a reasonable assumption that the metabolite story—effects of ambient temperature; extreme underfeeding—does not adequately cover *B. indicus* cattle and their crosses (especially those used for milk production), buffaloes and goats?

In countries with defined dry and rainy seasons, the ideal time of insemination is determined by the associated fluctuation in nutritional status (Lotthammer 1991). Underfeeding during growth delays puberty; while in late pregnancy delays the resumption of oestrus after parturition; and during the post-partum period reduces pregnancy rates (McClure 1994). McClure (1994) cited undersupply of energy as being the major cause of undernutrition, which also reflects inadequate N for optimum rumen function, particularly with cattle subjected to tropical dry season feeding (ARC 1984).

With *B. indicus* cows in the dry tropics, Fitzpatrick (1994) cited interactive effects of undernutrition and suckling as the cause of prolonged calving intervals. Feeding of pregnant cows, in the last six to eight weeks of gestation, with a high-energy supplement, was recommended to increase pregnancy rates and reduce the calving to conception interval. Reducing suckling episodes to one per day when the calf was a month old, did not reduce calf weight or milk yield but did reduce the calving to conception interval (Fitzpatrick 1994). Tegegne et al. (1994), Margerison (1996) and Mukasa-Mugerwa et al. (1997) noted the benefits of adequate energy intake or supplementation and partial suckling on yield and reproductive performance.

Adequate levels of nutrition are rarely available for smallholder dairy cattle in the tropics (Mukasa-Mugerwa et al. 1997), although *B. indicus* cows provide 80% of the regional milk production (this suggests that improved nutrition could reduce the number of lactating cows required and, therefore, the amount of the available feed used for maintenance purposes). Mukasa-Mugerwa et al. (1997) studied the effects of body condition at calving and subsequent energy utilisation on the length of the post-partum anoestrus period and concluded that: thin cows recovered body condition at the expense of calf growth rate, together with a longer period of anoestrus and a longer calving interval. Cows in better condition produced bigger calves, which grew faster, and although they lost weight in the first four months of lactation their anoestrus period and calving interval were shorter than their thinner counterparts. Conceptions occurred when body condition scores, as measured on a scale of 1 (emaciated) to 9 (obese) were around 4.7 (Nicholson and Butterworth 1986).

The farmer judges the reproductive success of his/her livestock by the number of live births within a defined time scale (often per year). However, cessation of pregnancy in animal can occur at a number of points. Ball (1997) defined the bovine conceptus as an embryo from day 14 to 45 after fertilisation, when it becomes a foetus. A number of reasons for an increasing number of late embryo and early foetal losses are given, including heat stress. Amongst other factors associated with this type of loss, Ball (1997) suggested undernutrition as being by far the most important. Ducker et al. (1985) found that with intensively managed Friesian dairy heifers those with the highest daily energy output, at the time of breeding, had the longest calving intervals. Although two planes of nutrition were applied before and after calving, milk yields were similar for all groups (±18 kg per day). Zebu and zebu crossbred cows, giving comparatively little milk but with a diet of natural grazing only, will also have an extended time between parturition and conception (Zerbini et al. 1995). Zerbini et al. (1995) found this to be worsened by work.

Zerbini et al. (1996b) found that cows, which had received natural grazing only for two years and had not cycled for 790 days, responded to an improved diet, those on moderate hay alone conceiving in 86 days and those on the hay plus pasture in 63 days.

In a long-term comparison of indigenous and exotic breeds and crossbreds in a semi-arid area, Moyo (1990) found that the weight of yearling produced per cow was highest for a small, indigenous (Mashona) breed. Whilst the Mashona weaner was the lightest, the calving percentage of the Mashona was the highest, including those of larger indigenous breeds and their crosses (of the seven terminal sires used, the Friesian represented the dairy breeds).

Buffaloes on a low plane of nutrition increased the length of the oestrus cycle, especially in the summer, and oestrus detection was difficult compared with adequately fed (NRC 1971) buffaloes. Conception was also higher in the adequately fed group (Kaur and Arora 1982).

Kaur and Arora (1982) suggested that adequate feeding reduced summer stress as a factor in disturbed oestrus cycles in buffaloes. Ball (1997) cited heat stress as a cause of embryonic loss. Heat stress during early pregnancy reduced conceptus weight and possibly increased embryonic loss in *B. taurus* cattle (Biggers et al. 1987), although the cows were well fed throughout the 17 days of the experiment. (Similar information is required for underfed zebu cows).

Robinson (1990) concluded that there are few experiments conducted that considers implications of nutritional effect in overall reproductive life span. These are important because nutritional regimens that maximise a response at one point can have carry-over effects that could be counter-productive at a later stage.

In the tropics, natural matings are more common than AI. Undernutrition has been described to play an important role in semen quality (Brown 1994), thus affecting fertility in the dairy herd. AI of goats is not an option for most farmers (reliable AI services would allow a reduction in the number of bulls kept, allow an increase in genetic potential for milk yield and possibly improve herd health).

Health

Veterinary conditions may be caused by undernutrition or malnutrition, some exacerbated by it and some, including infectious diseases, not related to nutrition but, if not fatal, resulting in animals with greatly reduced production potential. Aspects of health, which impinge on the use of nutrients include: lack of appetite and a drop in productivity (growth, draft output and milk production); delayed conception (see reproduction); death. Provost (1990) discussed disease as a constraint to livestock production with emphasis on tick-borne diseases. Trypanosomiasis and helminths were also discussed.

In Côte d'Ivoire, mortality rates in traditionally managed flocks of sheep and goats up to 365 days of age were 48.1 and 44.2%, respectively. In older animals the rate in the two species was approximately 22% (Armbruster and Peters 1993). In Zimbabwe, kid deaths in smallholder goats are also up to 50% before weaning (Sikosona, personal communication). In the North-West province of Cameroon, in 41 recorded goat herds 27.4% of animals had helminthias problems, 20.3% tick infections and 7.2% were suffering from malnutrition (Nfi and Ndamukong 1997). In Mexico, annual mortality rates in goats were 21.5%, with pneumonia and malnutrition being larger problems in older goats and enteritus more common in younger animals (Mellado et al. 1991). These examples suggest that a large number of breeding does die before they reach their full breeding potential, as maximum fertility is reached at 5–6 years of age (Payne 1990).

In the Kabate area of Kenya 46.8% of calf deaths occurred in the first two months of life (Mulie et al. 1995). Baker et al. (1994) reviewed the role of indigenous animals and adaptation in reducing the impact of parasites and disease.

Ticks

In Africa, ticks and tick-borne disease are the major constraint to increased livestock production (Pegram et al. 1993). They also account for a large portion of the money used in veterinary control programmes. Depending on season, losses of live weight in cattle of between 0.47 and 1.52 g per engorged female tick have been recorded (Sutherst et al. 1983). Live weight was recouped through compensatory growth at a later stage but in females, in a fixed season breeding programme, such losses could result in missed conception, especially in heifers, where 65% of mature weight is recommended at oestrus (CPA 1988). In Zimbabwe, live weight losses of cattle of 4 g per engorged female of *Rhipicephalus appendiculatus* and 10 g with *Amblyomma herbarium* were reported (Norval 1990). This can amount to 20 kg lost live weight gain in steers over 3.5 months (Norval et al. 1989). Norval et al. (1989) also reported higher incidence of screwworm where adult ticks were present. In many areas maximum growth and tick burden occur at the same time (hot wet season), so the opportunity for compensatory growth is not always available unless supplementation is given. Kategile and Mubi (1993) discussed replacing the traditional control methods, based on plunge dipping, by combining immunisation and reduced dipping. Apart from the financial cost, the energy expended (especially in the summer) and stress caused to cattle that may have to walk several kilometres to a central dip tank represents a tare on the feed resource. A successful control programme will depend on the wildlife population, the co-operation of livestock owners and, if necessary, the scope for enforcing controls. Norval (1990) concluded that, in many cases in Africa, strategic rather than intensive tick control policies were justified.

In India, ticks infections reduce digestibility and weight gain in goats (Pandita and Ram 1990). Pandita and Ram (1990) also cited lice and mites as causing the same problems. In Tanzania, ectoparasites affect up to 98% of goats within a flock, infestations being higher in tethered animals (Kusiluka et al. 1998).

Perry and McDermott (1998) discussed the need to assess the impact of disease on livestock productivity and the cost of control, from research through to implementation. Using tick borne diseases as the model, they described five epidemiological tools that contribute to impact assessment:

1. geographical information systems to estimate disease distribution
2. mathematical models to quantify infection dynamics
3. observational field studies to link infection status with production loss
4. statistical models to enhance study design and
5. spreadsheet models for economic impact assessment.

Trypanosomiasis

Areas best for producing forage in the tropics are those rated semi-humid or humid. In Africa these account for about 35% of the available land and are the areas inhabited by the tsetse fly, the vector for trypanosomiasis (Perry and McDermott 1998). To survive and produce, ruminants will need to be trypanotolerant (d'Ieteren 1996). Paling and Dwinger (1993) raised the issue of the potential use of the N'Dama breed as the basis of trypanotolerant cattle. Agyemang et al. (1990) summarised the effects on production and the economic impact of the disease. They reported a loss of around 25% of milk for human consumption from infected N'Dama cows, but no loss of calf growth rate. An increase in feeding level for infected cows is suggested.

In sheep, plane of nutrition was found to influence survival rate from infection (Reynolds and Ekwuruke 1988). They also reported reduced intake and growth rate in lambs and reduced birth weights, from infected ewes. Tsetse control schemes rely on the active participation of local farming communities (Slingenbergh 1992). There is extensive collaboration between ILRI and many national agricultural research services on control of tsetse and developing trypanotolerance in livestock (d'Ieteren 1996).

Internal parasites

Internal parasites or gastro-intestinal nematodes are common throughout the tropics, especially during wet seasons. Control is based on the use of anthelmintics, to which there is now some resistance (Saithanoo et al. 1996). Saithanoo et al. (1996) suggested grazing management and the breeding of tolerant animals (local Thai goats exhibit greater resistance than Anglo-Nubian crossbreds) as alternative methods of control. In Tanzania, Kusilaka et al. (1998) reported that up to 98% of goats might have internal parasites, high levels of infestation being found in stall-fed animals. Niezen et al. (1993) reported reduced faecal egg counts in lambs receiving diets containing condensed tannins. Both increasing the tannin (Quebracho tannin) and protein content of the diet reduced faecal egg counts in a trial where lambs affected with parasites had a reduced growth rate (Butter et al. 1998). They also suggested introducing tanniferous feeds for some tropical situations.

Infectious diseases

The major infectious disease of ruminants is Foot-and-Mouth disease. It is not generally fatal for adult animals indigenous to the tropics (Miller and West 1959; CPA 1988). However, production losses can be severe and rigorous control programmes are needed. Saxena et al. (1990) estimated that in India production losses from reduced yields and delayed conceptions in indigenous and crossbred cows and buffaloes equals Rs 12.5 billion in foreign exchange and Rs 18.7 billion in domestic economy surplus. In volume, this equalled to 3.51 billion litres of milk or 6.5% of the national output (there are no estimates of the scale of losses from calf deaths). Loss of animal draft power can be substantial (Payne 1990).

Premature death and/or impaired efficiency of use of nutrients are a waste. Veterinary medicine based on drug therapy is usually expensive and may not always be available even if the means to purchase are. Parasites and diseases are not new problems and for most there is claimed to be a traditional cure (ITDG and IIRR 1996). Combining modern and traditional veterinary practices together in selecting and developing adapted animals and improved control measures, will contribute to an increase in output from a limited feed resource. The conditions discussed here are thought to be some of the most costly, because of their widespread occurrence.

Adaptation to undernutrition

Compensatory growth

According to Matulis et al. (1987), in the tropics seasonal patterns of rainfall determine the cyclical nature of growth of vegetation and live weight gain followed by live weight loss of up to 20% observed in animals dependant on grazing. This could be acceptable where livestock keeping is not the only means of survival. Cattle that have experienced a period of undernutrition have higher than normal rates of weight gain when re-alimented (Matulis et al. 1987). The amount of compensation, when re-alimentation occurs (normally after the onset of the next rains) will depend on the length of the period of underfeeding; the severity of underfeeding and the amount of feed available in the re-alimentation period (O'Donovan 1984). The severity of the effects of underfeeding will also depend on the defensive mechanisms the animal is able to employ (Ortigues 1991).

The timing of rainfall and, therefore, vegetation growth are not controllable by farmers (only few have access to irrigation). Of the other major causes of underfeeding some are manageable and for these some working research and development interventions may be required.

Whilst ameliorating the factors listed in Table 2 may be possible, the live weight loss and gain cycle is an important factor of livestock management in much of the tropics.

Many of the experiments concerning compensatory gain are of a short-term nature and in most full recovery are not achieved (O'Donovan 1984). In a trial over two dry seasons *B. indicus* steers were either fed in both (HH), not fed in either (LL) or in one (first or second) (HL; LH) dry season. They were slaughtered either after a wet season recovery period or after 90 days of pen feeding following the wet season recovery. The carcass weights of HH were 17 kg more than LL, regardless of time of slaughter, with HL and LH being intermediate (Smith and Manyuchi 1992) (Table 13). Whilst rainfall was similar in both seasons, the pattern of distribution was markedly different, which was reflected in the apparent severity of underfeeding between the two dry seasons (it also demonstrates the difficulty of interpreting climatic data). The financial implications of these results may have been greater with heifers destined for breeding than with steers. In another trial, Manyuchi et al. (1991) compared dry season underfeeding in *B. indicus* steers of two ages, 8 and 20 months at the start of the six-month trial. There were no differences in the degree of weight loss or recovery between the two age groups. The severity of undernutrition, however, influences the recovery period and if the period of underfeeding is too long, the animal might not be able to fully recover. Hopkins and Tulloh (1985) showed that lambs severely underfed for five weeks of their post-natal life and then fed *ad libitum,* did not recover fully after 12–14 months.

Table 13. *Carcass characteristics of steers after receiving supplements in the first (1988 HH, HL) or second (1989) dry season (HH, HL) or no supplementation (LL).*

	Group			
	HH	HL	LH	LL
Slaughtered off veld				
Initial live mass (kg)	156.2	155.8	159.0	152.8
Final live mass (kg)	356.2	331.7	344.4	306.9
Cold carcass mass (kg)	165.0	150.2	163.6	146.4
Carcass length (cm)	116.2	115.4	115.6	111.9
Kulling out (%)*	46.3	45.3	47.5	47.7
Pen-fed prior to slaughter				
Initial live mass (kg)	162.0	149.2	151.6	158.4
Final live mass (kg)	357.0	326.8	345.2	314.2
Cold carcass mass (kg)	248.7	231.3	239.3	221.4
Carcass length (cm)	120.1	119.0	119.5	116.7

* Cold carcass mass as a % of final full live mass.
Source: Smith and Manyuchi (1992).

In an experiment with lambs (Kamalzadeh et al. 1998) reported that feed restriction reduces carcass and organ weights. The early maturing parts, head, feet and visceral organs, were less affected by underfeeding than other parts. However, after re-alimentation the most affected parts recovered most rapidly. The rapid gains at the outset of re-alimentation are often partly due to recovery in gut-fill. Maintenance requirements are also lower than for those not subjected to underfeeding.

Broster et al. (1989) underfed milking cows for one or two lactations and then observed the recovery over a further two lactations. No adverse effects of underfeeding were observed in the second lactation after the feed restriction was removed.

Compensatory gains are normally due to improved efficiency of feed use. Although weight losses are a composite of fat and protein deficiency, the latter is regained at a slower rate than lipids (Matulis et al. 1987). Swingle et al. (1979) reported compensatory growth of cull cows that were re-fed and found that tissue weight gain was approximately 50% lipid.

Thermoregulation

Throughout the tropics there are successful dairy herds under intensive management based on European dairy breeds, often Holstein–Friesians (HF). Levels of performance are similar to those achieved in temperate conditions. In the smallholder situation, with a lack of sophisticated inputs, production of the HF drops to around that of local *B. indicus* breeds (Table 5). Measurements of adaptation to high ambient temperatures usually include respiration rate, rectal temperature, food intake and water intake (Table 14).

Table 14. *The effect of ambient temperature on animal temperature, respiration rate and food and water intake.*

Breed source	Temp. (°C)	Water temp. (°C)	Respiration rate (per min)	Rectal temp. (°C)	Skin temp. (°C)	Body temp. (°C)	Water intake (kg)	Feed intake (g/100 kg LW/day)	Coefficient of adatability*
Bali cattle[a]									
Male			66	39.4	37.6				
Female			61	39.2	37.1				
Cool season			52	39.1	37.1				
Hot season			75	39.5	37.6				
Friesian cattle (1)[b]									
Summer			45.2		29.5	38.8			
Autumn			53.9		28.9	38.7			
Winter			30.1		33.2	38.5			
Sunlight			70.1		28.3	39.8			
Shade			29.1		30.5	38.9			
Friesian[c]	20		46	38.6				2875	
	30		89	39.8				2384	
	38		104	40.3				1871	
Brahman × Fr	20		38	38.4				2714	
	30		64	38.9				2594	
	38		81	39.3				2222	
Holstein heifers[d]	24	10	24	38.5	33.5	37.7	6.9		
		20	31	38.8	34.1	38.1	7.3		
		30	41	38.8	34.6	38.2	7.9		
	29	10	27	38.6	35.0	38.1	7.3		
		20	32	38.8	35.5	38.3	7.4		

Cont'd.

Table 14. cont'd.

Breed source	Temp. (°C)	Water temp. (°C)	Respiration rate (per min)	Rectal temp. (°C)	Skin temp. (°C)	Body temp. (°C)	Water intake (kg)	Feed intake (g/100 kg LW/day)	Coefficient of adatability*
		30	46	39.0	35.9	38.6	8.0		
	34	10	26	38.7	36.3	38.4	8.0		
		20	40	38.9	36.8	38.7	8.0		
		30	47	39.2	37.1	38.9	8.0		
Bunaji (2)^{e}				38.4	30.4				2.35
Bunaji (3)				39.3	38.9				2.72
Sokoto Gudali (2)				39.0	38.3				2.69
Sokoto Gudali (3)				39.1	42.6				2.87
Friesian × Bunaji (2)				39.3	42.3				2.87
Friesian × Bunaji (3)				39.7	51.8				3.27

*RT/38.33 + RR/23.

(1) Values were lowest in morning and highest in afternoon. (2) Cool season. (3) Hot season.

Sources: a. Kasa et al· (1997), b. Shafie and El-Sheikh (1970), c. Kellaway and Colditz (1975), d. Purwanto et al. (1996), e. Buvanendran et al. (1992).

High ambient temperatures, lying outside the thermoneutral zone, are normally accompanied by a higher heat energy expenditure (Derno et al. 1994). Resting heat production, based on an ambient temperature of 17°C, was better maintained at higher temperatures (22, 27, 32 and 37°C) by Hariana cattle than by their crosses with European dairy breeds (Jersey, Brown Swiss, Holstein–Friesian) (Singh and Bhattacharya 1991). In the same trial, intake of ME was highest in the Hariana and this breed had the lowest rectal temperature and respiration rate. With the crossbreds the performance of the Jersey was closest to the Hariana. Temperatures at which changes in thermosensitivity are occurred are predicted from this trial (Table 15). Estimated falls in ME intake and heat production, when ambient temperature rises from 17 to 32 and 37°C are also given (Table 16).

Table 15. *Calculated values for ambient temperatures above which different indices of thermosensitivity depart significantly from adjusted mean values at 17°C.*

		Genetic group			
Response	Exposure day	Hariana	Jersey × Hariana	Brown Swiss × Hariana	Holstein–Fr × Hariana
Heat production	8	32.0	29	27.5	27.0
	18	34.0	31	29.0	29.0
Respiration rate	5 to 7	29.0	26	24.5	25.0
	15 to 17	30.5	26	26.0	26.0
Rectal temperature	5 to 7	32.5	29	27.5	27.5
	15 to 17	34.0	30	28.5	27.0

Source: Singh and Bhattacharya (1991).

Table 16. *Decrease in metabolisable energy (ME) intake and resting heat production (H) (kJ/kg$^{0.75}$ per day) at 32 and 37°C from that at 17°C.*

	Test temperature (°C)	Exposure day	Genetic group			
			Hariana	Jersey × Hariana	Brown Swiss × Hariana	Holstein–Fr × Hariana
ME intake	32	8	111	126	155	165
		18	143	149	163	219
	37	8	215	210	218	224
		18	237	232	209	260
H	32	8	35	52	62	70
		18	27	41	54	51
	37	8	58	66	68	77
		18	52	93	65	77

Source: Singh and Bhattacharya (1991).

Schematic representation of the changes in thermoregulation within the animal is given in Figure 1.

In comparing zebu and Friesian–zebu crosses in Nigeria, Buvanendran et al. (1992) found that respiration rate was the most reliable indicator of heat stress, with few differences being recorded in rectal temperature. Kahoun (1971) measured rectal temperature in West African Shorthorn and N'Dama cattle over the first 10 days of exposure to continuous high temperatures (over 29.5°C). In the first five days increases in body temperature were noted but these subsided during the second five days, indicating an ability to tolerate heat in these two breeds.

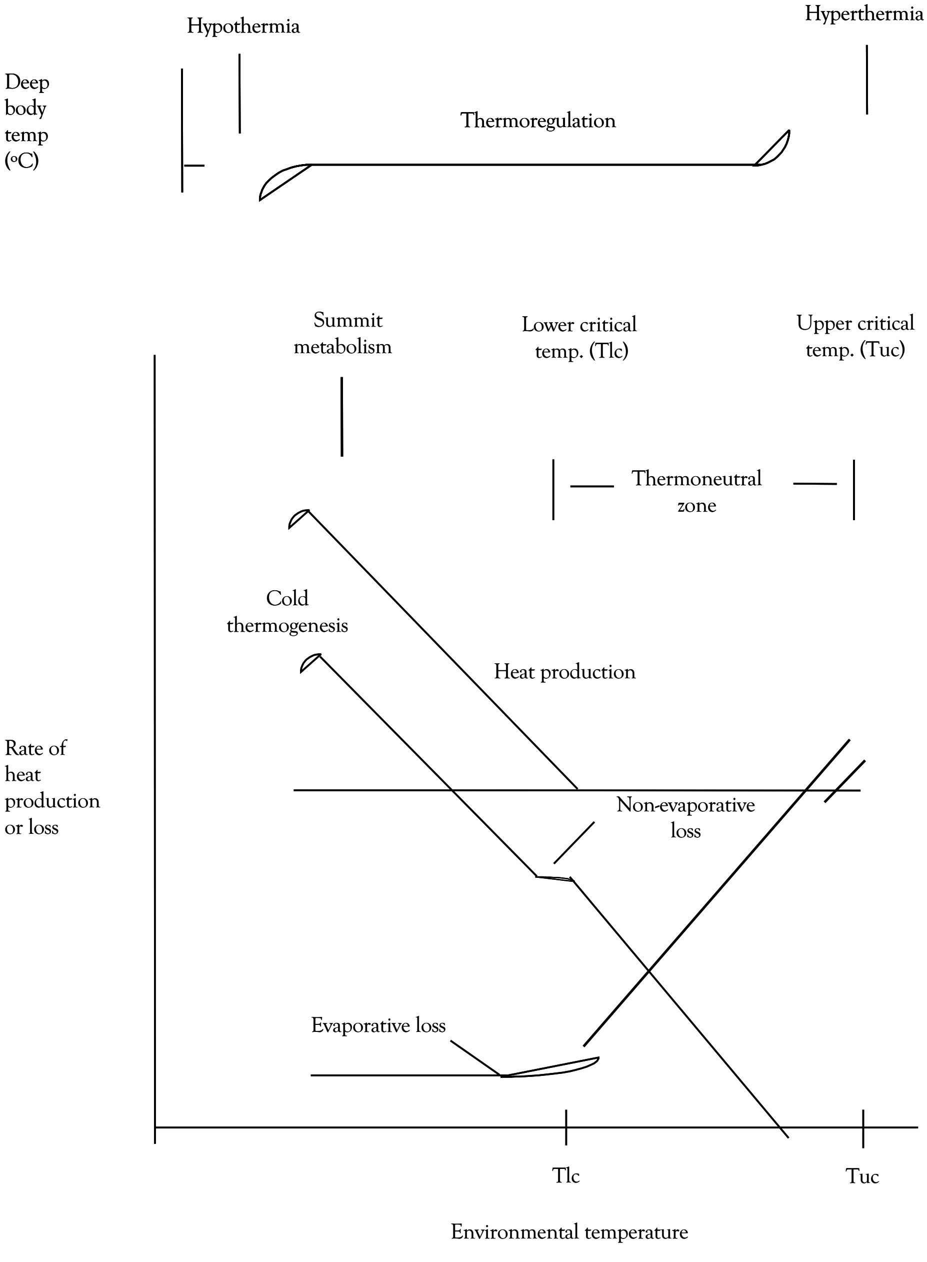
A negative relationship was observed between heat tolerance (rectal temperature, coat length) in Senepol and Hereford cows and time spent grazing (Senepol 10.5–10.7 hours' Hereford 9.3 hours) (Hammond and Olson 1994). Jan and Nichelmann (1993) found that in the rainy season Friesians spent less time grazing than Siboney de Cuba cows, and spent more time in the shade.

When comparing temperate and tropical breeds of *B. taurus* cattle Spiers et al. (1994) found that Romosinuano calves and their crosses showed fewer signs of distress, with greater coetaneous evaporative water loss and less physical insulation than Aberdeen Angus calves. It is suggested that reduced metabolic heat loss may also have been a factor. Finch (1985) reported lower non-evaporative heat loss in Shorthorn steers compared with Brahman and Brahman crossbreds. The Shorthorns achieved less tissue conductance and stored body heat, thus increasing temperature. The responses of the crossbreds were intermediate, but closer to the Shorthorns.

Kellaway and Colditz (1975) found that although Friesian steers drank more water than Brahman × Friesian steers their calculated evaporative losses were lower and the N loss in the urine more marked. Digestion in the two genotypes was similar.

Optimum productivity from European dairy breeds in the tropics depends on provision of adequate facilities and resources. Ansell (1981) discussed the importance of correct shade design (adequate air flow around the animal and air space above). Ansell (1981) and

Flamenbaum et al. (1984) discussed the value of wetting the coat, as a means of cooling, although this technique is not appropriate for most smallholders.



Source: CSIRO (1990).

Figure 1. *Effect of environmental temperature on thermoregulation by the animal.*

In summary, for cattle increasing ambient temperature increases the demand for drinking water, changing the optimum pattern of drinking, and reduces feed intake. In all the comparisons indigenous breeds were judged to be better adapted to the conditions than exotics, with crossbreds being intermediate (occasionally better than either parent). Of the exotic dairy breeds, the Jersey is preferred (Singh and Bhattacharya 1991; Muller and Botha 1993). Westhuysen (1973) suggested that metabolic factors due to heat tolerance in tropical breeds (low thyroid and raised adrenocortical functions) are related to low productivity; selection for one set of traits could impair the other. There is good evidence on the effects of heat stress but more is required regarding the primary physiological processes.

In buffalo, the Murrah had more sweat glands than either Surti or nondescript types at 245, 164 and 225 per cm^2 of skin, respectively. The glands of the Surti were judged as having a low efficiency and they also had the thinner epidermis. In heat tolerance coefficients, Surti was rated as the best followed by non-descript and Murrah (Saravanakumar and Thiagarajan 1992).

In goats, long haired, light coloured types were found to be more heat tolerant (judged by diurnal changes in rectal temperature, respiration and pulse rate) than short-coated black goats (Archarya et al. 1995). Black goats drank more and ate less than white goats during the hottest (39.5°C) time of the day. Although goats exhibit some heat resistant characteristics they may be susceptible to heat stress. The critical temperature at maintenance is probably between 25 and 30°C. Attention is drawn to the lack of evidence for the lactating goat kept in a warm environment. Studies with Australian feral goats (Dahlanuddin and Thwaites 1993) suggested that ambient temperatures of about 40 to 45°C are about the limit of their endurance and adaptation to these high temperatures is dependant on the previous environment. Feed intake dropped from 1316 to 466 g/day and water intake rose from 2674 to 6892 ml/day, as ambient temperature increased from 25 to 45°C (Dahlanuddin and Thwaites 1993).

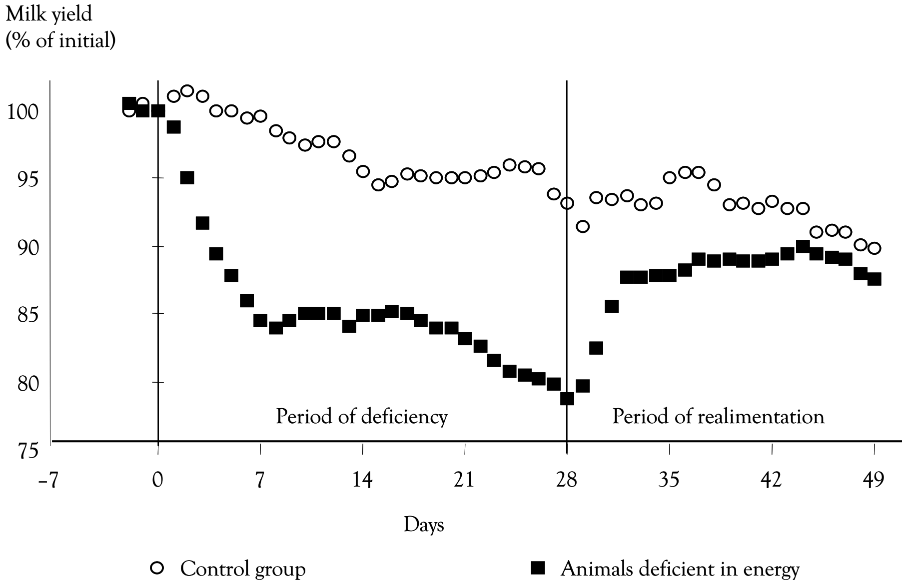
Reduced metabolic rate

Undernutrition results in a rapid response of the liver to a change in feeding level (Taylor and Murray 1991) and a decrease of visceral tissues in relative proportion to body weight (Ferrel and Jenkins 1984; Burrin et al. 1990). A decrease in the proportion of metabolically active visceral organs, therefore, results in reduced total body energy expenditures during adaptation to nutrient restriction (Burrin et al. 1990). Similar effects of undernutrition on visceral organs have also been observed in goats. Liver weights were significantly different among female non-lactating, non-pregnant Nubian goats fed at different feeding levels (Mora et al. 1996). The authors concluded that adult goats have the capacity to adapt to medium and long-term undernutrition and the liver is important as a source of generating energy and for sustaining protein turnover, which could be essential when grazing in semi-arid areas.

Further research is required on effects of nutrient intake on visceral organ metabolism and how quickly the visceral organs can recover with availability of feed (perhaps during the wet season).

Carry-over effects on milk synthesis

Reaction of lactating Simmental (pure-bred and crossbred) cows to mildly deficient energy supply (about 25% below requirements) and of the subsequent re-alimentation to a level of assumed requirements (according to the level of the control group) is illustrated in Figure 2. This is a typical response curve for modern dairy breeds.



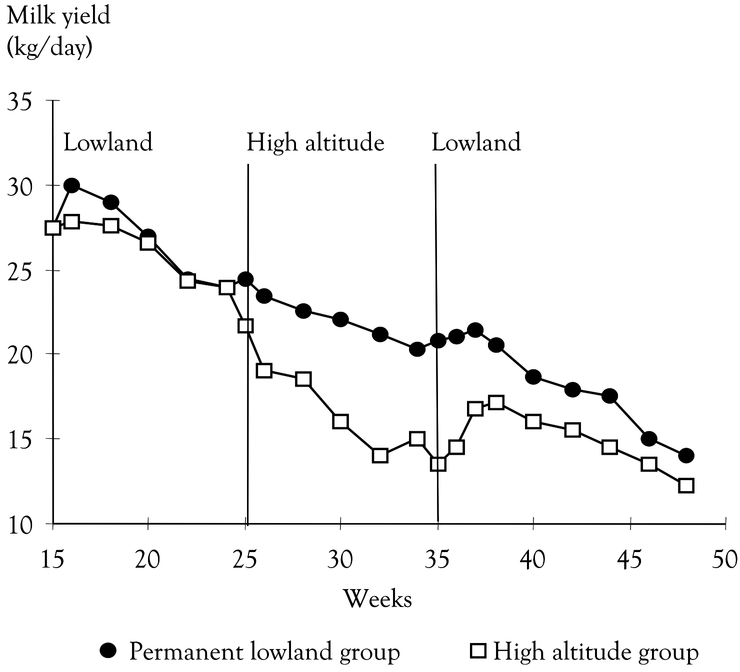
Source: Röhrmoser and Kirchgessner (1982).

Figure 2. *Direct and carry-over effects of deficient energy supply on milk yield.*

The first phase was an adaptive reaction to deficiency of about one week when a level in milk yield reduction is reached which accounts for about half of the lacking amount of energy. From then on, only the normal decline in milk yield occurs as the lactation progresses. Overall, the adaptation to mild energy deficiency needs a certain potential to use body reserves, but also heat energy loss (extra heat production for milk synthesis is lower) was reduced by an energy deficiency (Kirchgessner et al. 1983). The incomplete reduction in milk yield results from a homeorhetic mechanism, i.e. the support of the offspring even at the cost of the dam’s health (increasing incidence of ketosis).

In contrast to growing animals there seems to be, however, only a limited ability of lactating cows to compensate, or even over-compensate the depression in milk yield caused by deficient energy and/or protein in subsequent periods of re-alimentation (Figure 2) (Kirchgessner et al. 1986). Even if the amount of energy which was not supplied in the period of deficiency is supplied in a subsequent period, milk yield will only slowly return to the value of a constantly and sufficiently fed control group and no compensation of the milk lost in the period of deficiency occurs (Kirchgessner and Windisch 1989). Re-alimentation to a level similar to the energy supply of the control cows will not support an increased milk yield of more than about half of the difference between the control cows and the previously underfed cows (Figure 2). Direct and carry-over effects are similar when instead of energy alone both energy and protein supply are deficient (Broster et al. 1989; Kirchgessner and Windisch 1989; Windisch et al. 1989).

Summer grazing at higher altitude pastures (2000 vs. 400 metres above sea level, masl) has been demonstrated to selectively increase energy demands of lactating cows in a way which cannot be fully covered by a higher intake (Christen et al. 1996). Parts of the reasons for this kind of undernutrition (low oxygen pressure, steep hillsides, rough climate) are similar to those responsible for undernutrition in uplands of tropical countries, however, at a considerably higher level of nutrition. Comparing cows pastured at 2000 masl with cows at 400 masl fed to requirements caused the same direct and carry-over response curves in milk yield to undernutrition at high altitude summer grazing (Figures 2 and 3) for controlled lowland conditions. Furthermore, summer grazing at higher altitude is accompanied by a certain pattern of response in hormonal and metabolic alterations (Kreuzer et al. 1998), which also might be partly typical for adaptation to tropical high altitude situations.



Source: Zemp et al. (1989).
Figure 3. *Effect of energy deficiency due to high altitude pasturing on milk yield.*

Further research is required to determine if there are also unfavourable carry-over effects, subsequent to periods of severe undernutrition, in milk yield compared with periods with better but still deficient energy and nutrient supply. Differences in metabolic use and partitioning of energy seem to be low between widely different modern dairy breeds such as Holstein, Simmental and Jersey (Münger et al. 1996). Additional energy supply usually results in a higher milk yield. In contrast, indigenous breeds in tropical countries, when severely undernourished after calving, initially replenish body reserves at the cost of lactation (Mukasa-Mugerwa et al. 1997). Exotics and crossbreds, although underfed for much of their lives, do not always respond as predicted by nutrient response models to concentrate supplements (Osuji et al. 1995b; Tanner, personal communication). A similar pattern was also found in growing cattle (Tembani et al. 1994). It is still unclear, if this is also valid for seriously underfed modern dairy breeds and if a lack of response in milk yield to additional feed could result from the kind of carry-over effects described above. The type of adaptation to subsequent periods of undernutrition is one of the crucial points in dealing with undernutrition since adopting costly strategies like the use of concentrate requires a reaction in yield which is visible to the farmer.

Lifetime performance

Most nutrition studies last for a few weeks, a season or at most a lactation. A combination of intake, growth rate, milk yield, nitrogen retention and digestibility will be measured for the stipulated period. Multi-lactation research, by comparison, is modest (Broster et al. 1993). In general, performance outside the trial period is regarded as irrelevant. However, the farmer is interested in lifetime performance. Broster and Broster (1984a, b) estimated the average life of a cow in a European dairy was three to four lactations. In a large number of cases the reason for wastage will be failure to meet production criteria imposed by the farmer. With smallholder owned cattle in the tropics failure to perform as a dairy animal is probably not a reason for culling, as the animal will still be capable of plowing.

Cows fed over four lactations at a combination of feeding levels (high, H; medium, M; low, L) gave 1 kg of fat corrected milk (FCM) per 20 MJ extra metabolisable energy, at the H compared with the L level of feeding (Wiktorsson 1979) (Table 17). Live weight losses were greater for cows on L (lactations 2 and 3), but when on a common diet (M) in lactation 4 these cows gained more than the H cows across lactations. The cows were entering their third lactation at the start of the experiment, and by the fourth experimental lactation 3 (2 on H; 1 on L) of the original 20 had dropped out. There was a linear relationship between milk yield at M and the yield response to H, so that cows producing 5000 kg FCM increased yield at H by 4.8% and cows producing 7000 kg FCM milk at M increased yield by 10% at H, demonstrating that high yielding cows give the best response to extra feed.

In a trial where feeding levels ranged from 80 to 110% of the recommended level (MAFF 1975; Broster et al. 1989), adverse effects of the lowest feeding level fed in the first lactation were apparent in the second but not in the third lactation. A higher level of feeding, with restricted or *ad libitum* roughage gave higher yields of milk, fat, lactose or protein. The pattern of live weight change was similar for all groups receiving a constant diet throughout the trial. Animals on the lowest level of feeding in the first lactation lost less weight at the start of the second than the other groups.

Differences between *B. indicus, B. taurus* and crosses between them should be added to the other subjects of study on multiple lactations (Broster et al. 1993). Dual purpose (milk and draft) crossbred *B. indicus* and *B. taurus* cows were worked and milked over a three-year period. By the end of the experiment only those, which were supplemented had conceived for the third time (Zerbini et al. 1996b).

Table 17. *Effect on milk yield of different rates of feeding of dairy cows over several lactations.*

	Days	Treatment sequence	Lactation 1	2	3	4
MJ ME/kg		M/L/L/M	4.9	3.98	3.87	4.82
Fat corrected milk (FCM)		M/H/H/M	5.02	5.86	5.99	5.08
FCM (kg)	1–70	M/L/L/M	1816	1842	1707	1701
		M/H/H/M	1897	1966	2122	1987
	1–305	M/L/L/M	5375	4657	4678	5452
		M/H/H/M	5525	5918	6037	5676
Live weight change (kg)	1–70	M/L/L/M	–4	–41	–16	–7
		M/H/H/M	–19	–1	–14	–34
	1–305	M/L/L/M	51	18	26	59
		M/H/H/M	38	62	30	16

Source: Wiktorsson (1979).

With beef cattle (*B. indicus*, *B. taurus* and their crosses) lifetime reproductive performance was highest in the smallest and yet the indigenous breed (*B. indicus*) (Moyo 1990). All genotypes grazed together, so it could be argued that the smaller animals were subjected to a lower degree of grazing pressure. Lifetime performance in this trial ended when more than 50% of cows showed severe tooth wear. The indigenous genotypes appeared to have no advantage, the Brahman showing least wear at 12 to 13 years of age (Dlodlo et al. 1988). Steenkamp (1969), however, found that tooth attrition was greater in exotic than in indigenous genotypes.

Africander cows from the same genetic pool, but reared in two different environments (fed; not fed) spent their breeding life in the rearing environment or were crossed over. Cattle from the fed line were consistently one to three per cent heavier than those from the not fed line. Weaning rate was reduced in the fed line cows bred in the not fed environment (Beffa 1995).

In summarising the crossbreeding work at Matopos since 1937, Beffa (1995) concluded that the indigenous purebred cow was the most successful of the beef genotypes (including Friesians as terminal sires) tested.

With goats lifetime performance is associated with the number of kids produced. Surveys have shown that indigenous does normally kid annually, although theoretically three kiddings in two years are possible. Reynolds (1986) suggested that strategic supplementation could improve small ruminant production. However, when comparing annual kidding without supplementation, and accelerated kidding with, or without, supplementation in a harsh environment, the 'accelerated' groups dropped behind the annual group over a two year period, there being a small advantage with accelerated kidding from supplementation (Sibanda and Ndlovu 1990a). Further work is needed to establish the optimum conditions. Weight of weaner was greatest in the supplemented accelerated group, but because of the high cost of feed return from sales was not economic (Sibanda and Ndlovu 1990b).

Manipulative strategies

Treating crop residues

Cereal residues

The dependence on and interest in crop residues reflects the pattern of below optimum stocking rates in good years and too high in bad years.

The importance of crop residues, particularly those from cereal crops, in dry season feeding in the tropics is beyond question, both for ruminants and other herbivores (e.g. working equines) (Nengomasha 1997). The quantities available, at the farm level, will vary according to the success of planting and rainfall in the growing season. Owen and Jayasuria (1989) estimated that annual production, based on 1981 statistics, was equivalent to 2 and 3 t dry matter per 500 kg livestock unit in Africa and Asia respectively.

To optimise the feeding value of residues, their negative and positive attributes must be considered (Sundstol and Owen 1984):

1. their CP content is low, so that maximum intake of roughage will not be achieved unless a protein supplement is fed
2. cell wall content is high, so that the rate and extent of digestion will be depressed unless the growth of cellulytic bacteria is encouraged (Campling et al. 1962; Chesson and Ørskov 1984).

These two attributes result in materials with ME content of less than 7.5 MJ/kg DM, thus defining them as poor quality feeds (Balch 1977). On the positive side ruminants are the only species of domestic livestock, which can use these materials that are an unavoidable by-product in prodcuing grain staples for human consumption (in this regard, as in the grazing of large tracts of natural rangeland, human and domestic ruminants are symbiotic). There are also practices and techniques to maintain or improve the feeding value of crop residues. These include:

1. Correct handling and storage: Rapid removal from the field after grain harvest minimises leaf loss and losses through senescence (Owen and Aboud 1988; Ncube, personal communication). Storage should be planned to minimise damage (weather, rodents) and to prevent forming mycotoxins (Ncube et al. 1993–94; Sampath et al. 1995).
2. Adding N, either as urea or protein to provide a balanced feed to maximise rumen digestion: This can be achieved by feeding straws and stovers in combination with protein feeds varying in quantity (Balch 1967), source (Smith et al. 1980) or with forage supplements (Preston and Leng 1987). Blocks containing both N, as urea and/or protein, energy (often as molasses) and, if required minerals can be fed in conjunction with the residues. Source of N supplement will depend on level of production required and cost (Preston and Leng 1984).
3. The gross energy of residues is approximately the same as all other foodstuffs but much of it is locked up in the relatively indigestible cell-wall material. Chemical treatment increases digestibility of cell walls: sodium hydroxide (Homb 1984) (strong, relatively dangerous, does not contain N, could pose an environmental problem, expensive and

difficult to transport) ammonia (Sundstol and Coxworth 1984) (slightly less effective, improves N status of treated material, not normally dangerous, expensive, difficult to transport either as liquid or in the anhydrous state) urea (adds N, can be transported in small amounts, suitable for smallholder use if cash and labour available). Improvements in intake and digestibility in various straws and stovers from use of these materials have been reported (Table 18). In addition to damping straws and stovers ammonia also acts as a preservative (Sundstol and Coxworth 1984).

Table 18. *Intake and digestibilities from chemically treated hay, straw and stover.*

Animals	Treatment	DM intake (g/kg $W^{0.75}$ per day)	DMD (%)	CP (g/kg DM)	Daily gain (g)
Friesian/Bunaji heifers[a]	Urea treated gamba hay and urea supplement	80.2	68		
	Urea treated gamba hay	75.2	64		
	Untreated gamba hay and urea supplement	77.8	66.3		
	Untreated gamba hay	61.1	53.6		
Sudan desert sheep[b]	50% sorghum straw	860.5 (g DMI total)			7.2
	50% sorghum straw treated with 7% NaOH	995.9 (g DMI total)			3.7
	50% sorghum straw treated with 7% NaOH and kurkedi	890.5 (g DMI total)			20.5
Ruminants (species not given)[c]	Rice straw	48	43	45	
	Rice straw and 5% urea ensiled	61	54	79	
	Maize stover	40	49	39	
	Maize stover and 5% urea ensiled	53	57	149	
	Millet stover	31	39	84	
	Millet stover and 5% urea ensiled	31	49	141	
	Sorghum stover	50	47	42	
	Sorghum stover and 5% urea ensiled	68	65	146	
Sheep	Maize stover	59.7			
		60.3			
Goats[d]	Maize stover – 20% wood ash	56.7			
		55.1			
	Maize stover – 4% NaOH	63.8			
		62.9			

Sources: a. Lufadeju et al· (1987), b. El Hag and Kurdi (1986), c. Fall (1990), d. Ramirez et al· (1992).

The use of urea, as a treatment agent, has taken off in parts of China (Shen 1993) (the government of China actively supports its use) and other parts of Asia, but its uptake has been limited in Africa. However, the potential to increase the supply of available nutrients from these materials is such that effective and acceptable techniques should be sought but 30 other chemicals have been considered, including local salts (e.g. magadi in East Africa), calcium hydroxide and oxide, potassium hydroxide and sodium carbonate (Owen et al.

1984; Owen and Jayasuriya 1989). Local materials have the advantage of being cheap and available, but as yet there are no practical alternatives on a large scale to NaOH and ammonia (or urea). Owen et al. (1984) emphasised the need for work on application methods. The cost, time requirements and potential hazards are possible indicators for the poor uptake of these techniques in Africa (other overriding factors in the production process may remove incentive for their use).

Magadi, a naturally occurring compound in East Africa, has a variable composition but is high in sodium (Musimba 1980). Treatment with magadi was less effective than that with NaOH on the *in vitro* digestibility of maize stover, rice and wheat straw at the same level of application. However, when NaOH was applied at 2% to maize stover it was less effective than magadi applied at 4.5%.

One of the major advantages of treatment with ammonia or urea, compared with NaOH, is that N is added to the residue, a characteristic of which is usually an unacceptably low level of N. However, in many parts of the tropics these materials are not easily available. A substitute material is urine, described as a wasted, renewable natural resource (Sundstol and Owen 1993). Composition of urine, from all species, is variable, as is the quantity produced (Owen 1993). There are practical problems in its collection, particularly from animals, which graze by day and are penned in loose yards by night. Culturally it may not be universally acceptable. However, research and analysis is required, together with assessing any potential disease risks and the practical aspects of urine treatment, where its use is acceptable.

The use of enzymes (cellulase and hemicellulase complexes) to assist fibre breakdown are currently being tested. Phipps et al. (1998) added thermophillic enzymes to whole crop wheat silage, harvested at two stages of maturity. There was some improvement in the nutritive value of the silages, particularly that harvested at the later date. The authors indicated an increase of 0.7 MJ metabolisable energy per kg DM. Research into these compounds is in its infancy, but as pointed out by Phipps et al. (1998), the potential for unlocking nutrients in tropical forage and crop residues is huge.

Efficient use of crop residues as animal feed (for other uses, see Sundstol and Owen 1984) normally involves removing them from the arable lands. They then may be moved to another area (e.g. sold to a peri-urban dairy farmer), thus moving nutrients off the farm to which they belong (also removing organic matter, a key factor to the water holding capacity of fragile soils). Where the use of fertiliser is limited the benefits of opportunistic use of a resource must be weighed against penalties to the whole farm system. Nutrient recycling within a farm (in this context ‘farm’ could mean the farmer’s arable land plus communal grazing, in which situation managing the ‘commons’ for livestock and non-livestock owners becomes an issue) or between farms needs researching.

Selection and rate of offer

Stovers and straws consist of a mixture of leaf, sheaf and stem material. Animals vary in the extent to which they select their feed. McDowell (1988) suggested that buffalo is the most efficient domestic species in its use of fibrous feeds because of low selectivity (a wide muzzle), large gut capacity and a greater extent of rumen fermentation than cattle (the last two features in a slow rate of passage through the digestive tract). Goats and sheep are the most selective feeders, with the shortest rumen retention time, thus making them the domestic species least able to cope with fibrous feeds (McDowell 1988).

Where residues are limited, they must either be rationed or reserved for critical periods (e.g. end of the dry season) or critical classes of stock (e.g. lactating animals or oxen needed for plowing). The use of residues will be most efficient in crop–livestock systems where the need to transport them is minimal and animals have direct access to the arable lands.

Owen and Aboud (1988) reported a number of experiments in which barley straw was offered at different rates to lambs and goats. They concluded that higher rates of offer resulted in a higher dry matter intake and selection of the more nutritious parts of the feed. The refusals could then be treated with alkali, thus reducing the cost of treatment, or offered to non-selective species such as cattle and buffalo (Owen and Aboud 1988; Wahed et al. 1990). In an experiment that involved differing rates of maize stover offered to lambs and steers, Smith et al. (1989) reported that intake increased with rate of offer. The intake increased as a percentage of that eaten, being higher for the lambs. With milking cows, intake increased with amount of stover offered and there was a non-significant increase in milk yield (Methu et al. 1997). Similar responses have been observed with sorghum stover when fed to sheep and cattle (Osafo et al. 1997).

Osafo et al. (1997) found that chopping the stover increased intake with sheep, but not with cattle. Physically treating stovers (chopping, grinding) is expensive, although coarse chopping (e.g. hand or electric operated chaff cutter) is occasionally possible. The smaller particles are often easier to feed and reduce the scope for selection. They also increase the surface area exposed to both chemical treatment and to microbial attack in the rumen.

Other manipulations and supplementation of residues

Most farmers have access to cereal residues. Many farmers in the tropics are prepared to forego planting high yields of grain to ensure an adequate stover yield and quality (McDowell 1988). Because of the structure of tropical straws and stover, van Soest (1988) found the response to chemical treatment to be less than with temperate straws. It was, therefore, suggested that, because there are also increased practical difficulties with chemical treatments in the tropics, breeding of cereal varieties with increased nutritive value in the residue or supplementing the residue with legumes should be considered. Possible supplements include cereal by-products, legume hays (e.g. groundnut hay), oil-seed cakes (usually the residue from on-farm extraction of oil, rather than an industrial process) and fruits and pods gathered from rangeland (Tanner et al. 1990; Ncube and Mubaiwa 1994) (Table 19).

Where available and collectable poultry manure is a useful nitrogen-rich supplement, both for grazing and stall-fed animals (Smith et al. 1987; Manyuchi et al. 1992). Its value will depend on whether it is mixed with litter, the feed the birds were receiving and the method of storage (a large portion of the N will be non-protein N).

Multi-purpose trees (MPTs) have several functions (Preston and Leng 1987), including animal feed, soil enrichment and fuel wood. Many planted, rather than indigenous, species are leguminous. Their value as protein supplements has been demonstrated in several feeding trials (e.g. Muinga et al. 1995; Abdulrazak et al. 1996; Topps 1997). Other possibilities include sugar cane, banana leaves and cassava tops (Preston and Leng 1987).

Table 19. *Grain and legume by-products fed as supplements to straw and stover offered* ad libitum *(daily intakes, live weight gain and dry matter digestibility, %).*

Animals	Treatment	DMI (kg/day)	Stover DM intake (g DM/kg $^{0.73}$)	DMD (%)	LWG (kg)
Kirdi sheep[a]	Rice straw and rice bran	0.736			
	Rice straw, rice bran, groundnut haulms	0.896			
	Rice straw, rice bran, cottonseed cake	0.829			
	Rice straw, rice bran, chopped cowpea vines	0.877			
Steers[b]	50% teff straw, 20% molasses, 25% nougcake, 4% bonemeal, 1% salt	6.9			0.628
	50% wheat straw, 20% molasses, 25% nougcake, 4% bonemeal, 1% salt	5			0.352
	50% oats hay, 20% molasses, 25% nougcake, 4% bonemeal, 1% salt	5.5			0.43
	50% native hay, 20% molasses, 25% nougcake, 4% bonemeal, 1% salt	5.9			0.477
Lambs[c]	Maize stover, cottonseed meal	52.5 (g DM/kg$^{0.73}$)	41.4	53.5	
	Maize stover, cottonseed meal, lablab	75 (g DM/kg$^{0.73}$)	41.6	60.3	
	Maize stover, cottonseed meal, cowpea	80.1 (g DM/kg$^{0.73}$)	43.8	60.0	
	Maize stover, cottonseed meal, pigeonpea	71.5 (g DM/kg$^{0.73}$)	37.2	57.9	
Sheep[d]	Sorghum stover	0.964		59.2	
	Sorghum stover and cottonseed cake (60 g/diet DM)	1.41		72.5	
	Sorghum stover and cottonseed cake (120 g/diet DM)	1.265		71.2	

Sources: a. Ngwa and Tawah (1992), b. Gebrehiwot and Mohammed (1989), c. Smith et al. (1990), d. Yilala (1990).

Trends in use of feed resources in developing countries

The main resources used as livestock feed in developing countries include pastures (herbaceous plants, fodder trees/shrubs), crop residues, cultivated forages, concentrate feeds (agro-industrial by-products, grains, feed supplements etc.) and household wastes. The relative importance of these resources varies across production systems. Agro-ecology, seasonality, land tenure and management practices at the farm level, among other factors, influence their availability (Williams et al. 1997).

Availability of grazing land is decreasing due to expansion of cropping to meet the demands for food, urbanisation and use of land for other activities such as industries (de Haan et al. 1997; Steinfeld et al. 1997). Reduction and fractionisation of grazing land do not necessarily mean a reduction in feed supply, but rather an increased grazing pressure and reduced access to feed resources during the growing season.

The trends are often associated with an increased risk of degrading grazing resource as and also with conflicts among different users.

Forage adoption

The adoption of introduced forages in tropical developing countries has been limited. Although the value of fodder banks in West Africa was recognised by agro-pastoralists, its adoption was slow (Elbasha et al. 1999). In East Africa (Boonman 1977) and South America (Ferguson 1992) reported adoption of grasses was more successful than that of legumes. In most cases the reason for poor adoption appear to be the lack of evidence of economic profitability or inadequate technical support, such as seed availability. In many countries, particularly in Africa, other problems such as land tenure and infrastructure need to be solved for the successful development and can add to the supply of human food, especially through developing most efficient production processes, such as dairy. Modelling and use of geographic information systems (GIS) can be used to predict where and how forages can fit into existing systems to provide livestock feed and enhance the sustainability of the resource base.

Crop residues

Crop residues are already the most important feed for ruminants in smallholder crop–livestock production systems of Asia and Africa and contribute substantially to the supply of nutrients for animals in mixed farms of Latin America (Williams et al. 1997). Availability and use of crop residues is increasing. The increase in availability of crop residues has not been proportional to the increase in cultivated land because crop breeding has generally put emphasis on grain yields. The feed value of crop residues has been largely ignored and resulted in varieties and hybrids that produce fewer residues than unimproved varieties. Applying new science in genomics and genetics to identify feed-related traits in major crops offers the potential to better target breeding to improve nutritive value of crop stover.

Genetic enhancement is one practical strategy to increase the quantity and nutritive value of cereal crop residues. For example, quality traits such as neutral detergent fibre (NDF), NDF digestibility and water-soluble carbohydrate content have been rated consistently as the highest priorities for improvement in forages (Smith et al. 1997; Humphreys 1989). The work of Burton (1972, 1988) with Coastal Bermuda Grass (*Cynodon* *dactylon)* demonstrated that significant progress could be made in genetically improving nutritive value. Although this is the most successful example in its kind, this experience with pasture species suggests that similar success is possible with cereals that are closely related taxonomically. Furthermore, given the genetic variation available for selection, it seems possible to increase both the quantity and quality of crop residues without sacrificing grain yield (Rattunde 1998). Significant natural variation in components of nutritive value can occur in cereals. For example, in rice, dry matter digestibility (measured *in vitro*) has been found to vary widely from 31–60% (Roxas et al. 1984; Roxas et al. 1985). Capper (1988) and Capper et al. (1992) reported similar variation in barley. Structural changes during plant growth, leading to crop maturity (Pearce et al. 1988) result from both genetic and environmental variation (Capper et al. 1992) and genotype × environment interactions affecting nutritive value (Goodchild 1998).

This approach involves research on cell wall chemistry, its genetic control and influence on yield and quality components, and plant breeding. Significant progress has been made recently on the chemistry of cell wall (Jung et al. 1993) its relationship with digestion (Besle et al. 1994; Jung et al. 1997) and the molecular basis for improving fibre digestibility (Hatfield et al. 1999). Possibilities for improving forage quality through genetic means have been established (Vogel and Sleper 1994). Once the heritable traits of importance are identified, the use of marker-assisted selection is a potential methodology that could accelerate developing improved dual-purpose genotypes. The major use of marker-assisted selection is to target loci corresponding to traits which occur late in the life-history of an individual, that are difficult to score directly and show a complex genetic basis with substantial environmental modification (Arus and Moreno-Gonzalez 1993). Thus feed quality parameters such as fibre digestibility appear to be traits for which marker assisted selection could be appropriate. These traits are difficult to score and are likely to have a complex genetic base, with multiple quantitative trait loci (QTL) contributing to the genetic variation. To date, genetic markers have not been identified for selection strategies aimed at desirable crop residue traits. However, molecular marker technology allowing marker-assisted selection by plant breeders is available (Sorrells and Wilson 1997) and could be used to develop markers for quality traits.

Genetically enhancing feed quality of crop residues is a long-term option that has not received sufficient attention in crop breeding programmes. There are presently few genetic improvement programmes for cereal crops that include selection for the quantity and quality of their residues for ruminant feed. However, the returns to investment in research appear to be high. Kristjanson and Zerbini (1999) conducted an *ex ante* assessment of returns to this type of research. They estimated that the net present value of the research for genetically enhancing sorghum and pearl millet is US$ 42–208 million with predicted internal rates of return of 28–43% and benefit–cost ratios of 15–69:1.

Supplementation and nutrient balancing

There is much room to improve feed utilisation and animal production through supplementation and nutrient balancing techniques. The underlying principles that determine the response to supplementation are reasonably well understood (Egan 1986). This is, in general, a mature technology and often, it is the low availability, the high cost of feed supplements or inadequate infrastructural support that limits their use at the farm level. This is particularly valid in the case of extensive areas where supplement delivery is difficult. Research is still required, primarily for fine-tuning the practice of supplementation under local conditions. This research needs to be viewed in the context of the production systems.

Manipulating feed intake

Production per animal is greatly influenced by the individual's capacity to consume feed. Voluntary feed intake is affected by both animal and feed attributes and also by environmental factors, but a great deal of the variability in intake is due to animal related factors. Grovum (1986, 1995), Ketelaars and Tolkamp (1991), Forbes (1995), Provenza (1995) and Weston (1996), among others, reviewed the neural, hormonal and biochemical mechanisms that control voluntary feed intake. A better understanding of these mechanisms can lead to technologies that increase production and feed use efficiency. Much of the research required is basic and strategic.

There are opportunities for increasing feed intake through feed management, for instance by letting animals to select the more nutritious feed parts using high feed allowances (Zemmelink 1986; Owen and Aboud 1988; Fernández-Rivera et al. 1994). However, this approach is likely to be adopted only in situations where availability of low quality feed is high, but it has limited potential in systems where the feed is in short supply. Thus, options to improve feed intake should be viewed in the context of specific production systems as part of a broad strategy to manage scarce nutrients.

Feed processing and conservation

Digestibility of feeds can be increased in various ways, such as chemical, physical and biological pre-treatments. There are opportunities for basic and strategic research related to cell wall chemistry and its modification by innovative means (Jung et al. 1993). A broad range of technologies based on feed processing is already available (Sundstol and Owen 1984), but in general, uptake of these technologies by producers has been slow. Socio-economic research is needed for identifying the conditions under which these technologies can be successfully applied and for their fine-tuning and adaptation to the prevailing farm conditions.

Seasonal shortages in feed supply are major constraints to increasing ruminant productivity in developing countries. In the tropics, conservation methods to improve availability of forages in the dry season and maintain their quality are poorly developed. Uptake of feed conservation techniques by smallholders and the use of methods for budgeting feed resources will help alleviate seasonal shortages, thereby improving year-round feed availability. Feed conservation strategies are highly specific to individual farms and to economic and climatic conditions. The low content of non-structural carbohydrates in many tropical feeds will likely limit the applicability of conservation methods to few forage crops. The environmental conditions prevailing in the tropics when feed availability and quality are highest will increase the need for investing in facilities to protect conserved forages from weather. Nevertheless, possibilities for success and uptake of feed conservation are high when the demand for better quality feed, the payoff to investing in labour and other inputs is high. Examples of these situations include market-oriented intensive fattening and dairy.

Manipulating rumen fermentation by feed additives

Other options to improve the efficiency of use of nutrients by ruminants include:

- manipulating rumen fermentation through the use of feed additives or by other means aimed at increasing the molar proportion of propionate in the end-products of fermentation
- protecting protein from degradation in the rumen
- increasing microbial yields
- decreasing methane production during the fermentation.

Research in these areas has already produced technologies such as feed additives (ionophores etc.), which are available and used extensively in feedlots in developed countries. There are still some opportunities for research to generate new or improve existing technologies (Martin 1998).

Selecting animals for improved feed use

In most tropical developing countries livestock have evolved under a highly fluctuating feed supply and disease challenges. The mechanisms of adaptation to these changes are not understood but they are thought to have a genetic basis. The large variation observed for feed intake and efficiency both among and within breeds and the moderate heritability values for feed intake (0.18 to 0.28) suggest that selection for altered intake is possible (Dickerson 1986; Ferrell et al. 1986). There are also some interactions between genotype and environment. Under favourable environmental conditions (climate, nutrient supply, less parasites) B. taurus cattle generally consume more feed and grow more rapidly than B. indicus cattle (Moran 1976; Frish and Vercoe 1977). However, in a more restrictive environment the greater production potential or feed intake of B. taurus is not realised (Frish and Vercoe 1984). It appears that there is potential for increasing forage intake or digestibility through selection of animals with larger rumen volumes, longer retention times of feed residues in the rumen and therefore higher digestibility (Grovum 1986). This area of research can result in animals that are better suited to use the low-quality forage available in the tropics, in more efficient compensatory growth. The approach can be criticised for being a long term and for the limited potential for disseminating the superior animals to a considerable number of livestock producers. However, as the production systems become more intensive and animal potential limits its productivity, selection of animals is an effective option to increase animal productivity.

Use of cereal grains by ruminants

Delgado et al. (1999) estimated that between 1982 and 1994 the global use of cereal grain as livestock feed increased at 0.7% annually. This included a decrease from 465 to 442 million tonnes in developed countries and an increase from 128 to 194 million tonnes in developing countries. In spite of this increased use of grain as feed, developing countries still use less than half as much cereals for feed as do developed countries. Projected trends estimate that by 2020 the global use of cereal grains, as feed will amount to 928 million tonnes, of which 409 million tonnes will be used in developed countries. Model predictions suggest that the use of concentrate feeds over the next decade will increase without significantly increasing cereal prices (Delgado et al. 1999).

Whereas non-ruminants compete for food with humans, a large proportion of the feeds consumed by ruminants in grazing and mixed systems have little or no alternative value. Poultry and pork production are most efficient on the basis of total food produced from total feed intake and also in terms of feed required for reproduction. However, cattle, sheep and goats produce more human food per unit of human-edible feed consumed, because more of their feed is obtained from materials that are not consumed directly by humans. CAST (1999) estimated that in developing countries the conversion rates of feed grain to human food (kg feed/kg of product) is 0.3 for beef, 1.8 for pork, 0.3 for sheep and goat meat, 1.6 for poultry meat, 0.2 for milk and 1.6 for eggs. Thus, in these countries ruminants produce more than 1 kg of human edible food for each kg of grain consumed.

Modelling undernutrition in ruminants

Introduction

Farming systems are extremely complex and need a detailed understanding of the interactions between various production systems within a given unit of land. Mathematical modelling is a tool to integrate knowledge and to develop priorities for research (France and Thornley 1984). Traditionally, experiments are designed to test a factor that influences the behaviour of a system. However, the number of factors can be so large that the availability of resources to test all factors is quickly overwhelmed. Furthermore, the results from a single site experiment cannot be transferred to another site and some experiments can take decades before any conclusion can be drawn. As the complexity of a system increases the value of quantitative systems models also increases (Walker 1993). Several types of models are available in animal production varying from simple empirical to complex mechanistic models. Empirical models are where input is directly related to output while mechanistic models require understanding and representing the mechanisms governing animal metabolism (France et al. 1987) and should apply to a wide range of conditions (Baldwin and Miller 1989).

Sustainability of crop–livestock systems in the tropics requires major improvements in nutrient cycling. Modelling could help identify ways of reducing nutrient losses in crop–livestock systems (Stangel 1994). Modelling studies conducted to date indicate a need for improved parameters to account for the effects of livestock on nutrient cycle dynamics under tropical conditions. This could be achieved by: integrating the effects of secondary feed factors treating diurnal variation in manure and urine production and increasing the potential of animal models to interface directly with soil models (Thorne 1995).

Feed evaluation systems and empirical models

There are different feed evaluation techniques employed to describe the nutritional value of tropical feeds (e.g. Madsen et al. 1997). While a critique of such techniques was not the objective of this review, the applicability of such systems *vis-à-vis* empirical and mechanistic modelling is considered.

Separate empirical feed evaluation systems have been developed in several countries perhaps due to the limited applicability of the models outside the environmental conditions in which they have been developed. The general curve of energy efficiency developed in five European countries and the United States do not include any correction for the nutritive level which creates major problems in less intensive production systems where the main part of the consumed feed is used for maintenance (Susmel et al. 1986). Similarly, van Soest (1994) reviewed systems for net energy evaluation and concluded that 'all existing European energy systems have been developed in northern Europe with cool climates and high-quality forages. Environmental effects that would lead away from proximate analyses and standardised digestion trials to include effects of intake on digestibility and problems of fibre quality have not been factors there. In southern Europe, where environments are more similar to those in the United States, US systems tend to be used'. Hence awareness is necessary of the highly empirical nature of these systems. Krishna et al. (1977) also pointed out that the 'Western' data used in India pertain to animals that are of larger body size, body weight and higher productive performance, and are adapted to different environmental conditions. Indian cattle by contrast are smaller both in body size and weight, are of low productivity and are adapted to adverse climatic conditions.

The comments on applicability of feed systems in various environments seem to apply to requirement of protein as well. For example, a report in CISRO (1990) clearly showed that the recommended minimum maintenance requirement for protein in ruminants by ARC (1984) did not apply in Australian conditions. Taking an example of a steer surviving on a poor quality dry pasture, which is not unlike conditions in tropical countries, the ARC (1984) estimate of 0.35 g TEN/kg $W^{0.75}$ implied the onset of a serious protein deficiency in animals even when their forage contains much more CP than the amounts commonly present in dry pastures.

Most of the models that are used for predicting animal performance (growth, milk production etc.) were derived by statistical resolution of large data sets (Gill et al. 1989) and empirical modelling. One of the disadvantages of such models is that the structure of the data set used to derive a model should be similar to the data set used for prediction (Gill et al. 1989). In addition, it would be extremely difficult to identify limiting nutrients when several types of feed are given to the animal. In contrast, mechanistic models could be applicable in a range of conditions and can more accurately predict nutrient balance problems. For example, the mechanistic model of Dijkstra et al. (1996a) identified a supply of nutrients to dairy cows in Brazil that was not balanced and allowed a precise evaluation of the optimal supplementation needed to improve milk yield.

Feed evaluation systems can shed some light on the nutritional content of animal feed. However, processes occurring in the reticulo-rumen significantly influence the amount and type of absorbed nutrients available for production (Dijkstra and France 1996). An understanding of the nutritional characteristics of feeds (and their interaction with rumen environment) other than their gross composition and metabolisable energy content is essential to obtain the most value from the feeds (Ørskov 1989).

Feed evaluation methods contribute to the development and use of mechanistic models by providing information required to drive the models. For example, Ørskov (1998) in his review on feed evaluation promotes the idea that feeds should be evaluated on their feed potential especially for ruminants fed on fibrous roughages. He proposed to evaluate roughages in terms of the size of the soluble fraction, the insoluble fermentable fraction and the rate at which the latter is fermented which can contribute to whole rumen models.

Nutrient supply models

Nutrient intake

While nutritional variables are extremely important in generating milk, fat, protein and other models, nutritionists may contribute the most towards establishing management goals through developing nutrient intake models. Such models are of increasing importance in the light of trends toward feeding complete rations and away from individual controlled feed intake (Brown et al. 1981). The applicability of such models, both in the tropics and at low levels of milk output (confounded by other output pathways), needs testing.

In his review of nutritional models for grazing animals, Walker (1993) stressed that the processes at the plant–animal interface (i.e. the transfer of nutrients from forage to the animal) have a greater effect on simulated and actual animal response than on any other transfer in the system because they affect the quantity and quality of the diet. He argued that models for grazing animals must include logic to interface forage availability with animal grazing behaviour, which at the moment is the weakest link in all animal production models. This is probably due to lack of research or observation in this area. Several other authors also agree that in most grazing animals and especially when feed is in short supply, nutritional management is primarily, and heavily, dependent on predictions of the amount and qualities of the pasture consumed (CSIRO 1990; Poppi et al. 1994).

Rook and Gill (1990) and Rook et al. (1990a, b) described empirical models of predicting the voluntary dry matter intake (DMI) of grass silages by beef cattle. They derived models using multiple linear regression, principal component regression and ridge regression to maximise correlation of observed and predicted intake. Similarly, Shem et al. (1995) predicted DMI, digestible dry matter intake (DDMI) and growth rates using multiple regression. They found high multiple correlation coefficients (>0.9) in predicting the DMI, DDMI and growth rates by cattle fed on crop residues and forages using the rumen degradation characteristics of the foods. Rook et al. (1990b) recommended further work to investigate the effect of genetic and environmental factors on intake. Further work is also suggested to define more adequately the available herbage in botanical, physical, chemical and spatial terms, and to conduct experiments in which factors influencing intake and selection are examined in an unconfounded way (Dove 1996).

Using a metabolism submodel, Poppi et al. (1994) derived a dynamic model to examine theories of intake regulation in growing ruminants. They considered that intake of a diet could be limited by the rate at which it can be consumed (especially relevant to animals that depend on grazing pasture), physical limit (e.g. gut fill) and metabolic processes. The model provided a way to integrate both physical and metabolic (genetic potential, heat dissipation and ATP degradation) pathways involved in intake control. Further research is required to adopt the approach to tropical low quality feed and test it experimentally.

A number of factors have to be considered when modelling nutrient intake in the tropics. For example, dry matter and organic matter apparent digestibilities tended to decrease with underfeeding and with the duration of underfeeding (Ortigues and Vermorel 1996). However, adaptation to undernutrition was observed to be achieved and apparent digestibility increased after about eight weeks of undernutrition (Grimaud et al. 1998). Considerations should also be given to high body temperatures that may restrict feed intake (Loewer et al. 1987).

Digestion and assimilating nutrients

Nutrients supplied to the tissue depend on the effect of the complex processes of digestion and metabolism on the feed inputs consumed by the animal. Thus, to predict how changes in feed inputs might affect expected outputs, a system, which represents a simplification of these processes, is required. Accurate prediction of whole animal metabolism requires models of nutrient digestion that convert the feed input into the nutrients absorbed from gastro-intestinal tract which then become available to the tissues (Gill et al. 1989).

Illius and Gordon (1991) developed a model of rumen kinetics to evaluate the prediction of intake and digestion of forages and the effect of body size on intake and digestion. The model predicted that large animals could obtain a greater proportion of their energy requirement from abundant poor quality foods than small animals. This is because the longer retention time in large ruminants increases digestive efficiency compared with small animals and would permit them to survive on lower quality foods.

When predicting ruminant production, rumen models are required because the amount and type of nutrients available for absorption differ from the profile of nutrients taken up, due to the activities of the rumen microbes (Assis et al. 1998). Dijkstra et al. (1996a) developed a mechanistic model of digestion and absorption of nutrients in cattle. Although the model was developed to assess possibilities of supplements for sugarcane-based diets in the tropics, it can be modified to suit other diets since the nutrient inputs to the model are derived from the chemical composition of the diet and the amount fed. These can be made available from other nutritional experiments using selected feeds and supplements.

In a review of rumen modelling, Sauvant and Ramangasoavina (1991) identified gaps in the knowledge of rumen digestion and recommended more work on the effects of chewing on particle size reduction and the function of the reticulo-omasal orifice. In a similar review of the development and current knowledge of models of rumen function, Djikstra and France (1996) concluded that no model exists that can accurately simulate rumen metabolism in all circumstances and highlighted areas of future research in relation to rumen modelling. They stressed that a representation of rumen microbial metabolism is important and aspects of microbial metabolism such as microbial distribution within the rumen, microbial interactions and chemical composition of microbial matter require further research.

By running simulations, various combinations of nutrient supply can be recommended. For example, Dijkstra et al. (1996b) found that small amounts of urea improved microbial efficiency and degradation of material in the rumen, but further increases could only be achieved with supplements containing protein–nitrogen. The results agree with experiments Smith et al. (1993) conducted in grazing Mashona and Brahman steers. They found that live weight gain and carcass weight increased with no or low concentrations of urea in a cottonseed meal supplement. The model can also be used to identify nutrient requirements for milk production, carcass weight etc. (France, personal communication).

At present, there is inadequate knowledge of N utilisation in ruminants. In their review of N transactions in the dairy cow, Dewhurst and Thomas (1992) concluded that there is an urgent need to provide predictive assessment of the efficiency of capture of rumen degraded N by rumen microbes and the efficiency of use of amino-acids by host tissues. This would lead to developing models that eventually help in deciding ration formulations that reduce urinary N excretion.

Manipulating rumen-available protein was beneficial to cows when they were in negative energy balance and sufficient body fat is available for energy demands. However, changes in rumen-available protein appeared to have less dramatic effects on production performance than modifications of energy although the two are highly interdependent (Nocek and Russell 1988). More studies are required on the effect of moderate and severe undernutrition on nutrient use. Dynamic equations and understanding of the biology are required to develop feeding systems that result in optimal protein and carbohydrate use (Nocek and Russell 1988).

Most models assume that there is a continuous availability of nutrients, which might not always be the case. In smallholder production systems in the tropics, changes of weight due to undernutrition are common. The effects of undernutrition need modelling with discontinuous feeding of animals to simulate dry season shortage of food.

Animal production models

Growth models

Empirical models

Animal growth has been studied using both empirical and mechanistic approaches. However, empirical models are much more common in the literature but their adaptation to new environments is inevitably limited. France et al. (1996) gave a simplified description of growth functions used in animal science such as the exponential, monomolecular, logistic and Gompertz functions. They outlined a new nested growth function that was capable of describing a range of diminishing returns and sigmoidal patterns and has a more mechanistic derivation compared with the Richards function. Salama and Schalles (1992) developed an empirical non-linear model to estimate the live weight of Egyptian water buffalo *(Bubalus arnee)* from body measurements. They observed a faster growth rate for males, compared with females, which were also larger at maturity. Such models could be important in day-to-day assessment of nutritional requirements.

Mechanistic models

Recently, interest in mechanistic models is increasing because these models can provide a tool for better understanding of complex growth processes and can be used in the development and evaluation of feeding strategies. Gerritis et al. (1997a, b) described and evaluated a mechanistic growth simulation model for ruminant calves between 80–240 kg live weight. The model provides a way of quantifying the connection between protein and fat retention and dietary input. To adequately simulate the effects of seasonal fluctuation in availability of food, experiments on the protein and fat retention at different fat and carbohydrate intake levels are required.

A sigmoid growth curve was simulated using a simple mechanistic description of a few fundamental processes leading to growth such as rates of protein synthesis and degradation without arbitrarily setting mature size of the animal (Danfaer 1991). The author also developed a mechanistic model to simulate the rate of body mass retention and the use of nutrients for either synthesis or oxidation in response to a wide range of different feed intakes.

Schmidely (1996) compared two of the six mechanistic models of growing ruminants that have particular relevance to smallholder production systems in the tropics. Gill et al. (1984) developed a mechanistic model that describes the metabolism of absorbed nutrients in a growing sheep. The model simulates energy metabolism in the animal fed forage and concentrate diets and the validations show that hypotheses tested in the formulation on energy use and efficiency of individual nutrients are in agreement with observed values (Schmidely 1996). France et al. (1987) also developed a mechanistic model, which is a simplification of the model developed by Gill et al. (1984). The model simulates the effects of varying nutrient absorption on energy retention and carcass composition. Both of the above mentioned models have a potential of being modified to study the effect of varying nutrient composition and period of undernutrition in smallholder production systems in the tropics.

Milk productivity models

Empirical models

Milk production has also been studied using empirical and mechanistic models of which the former are by far the most prevalent in the literature.

Lactation curves

Beever et al. (1991) reviewed empirical representations of the time course of lactation (lactation curve). They found that several types of mathematical functions (e.g. incomplete gamma function, gompertz, logistic, hyperbolic tangent etc.) have been used to model lactation yield, peak yield, time to peak yield and measures of persistency of lactation. However, they concluded that the parameters of any of the curves did not have a simple biological interpretation.

In spite of their limitations, empirical models are still widely used especially in the tropics. For example, Singh et al. (1996) used gamma function to describe first lactation curve in India. Khanna and Blalaine (1989) used various models to determine sampling intervals. Empirical equations are used perhaps due to their relative ease of fitting to experimental data or the lack of robust, mathematically sound and user friendly computer packages that can easily be adapted to conditions in the tropical countries.

Response to nutrients

For smallholder farmers to benefit from the low yields (1–4 kg/day) of zebu cows, they need to reduce the amount of milk consumed by the calf. Either weaning earlier or decreasing the amount of milk fed by nutritional needs of the calf being supplied from other sources could do this (Osuji et al. 1995a).

In SSA, most lactating cows are *B. indicus* and subsist mainly on low quality pastures and crop residues, which alone cannot support or increase milk production (Osuji et al. 1995b). Supplementing energy (molasses) and protein (cottonseed cake) to lactating cows increased live weight linearly according to the level of nutrient supplied. Increase in milk yield was high when both nutrients were added, rather than one. However, the increase in milk yield was marginal and the authors concluded that protein supplementation improved milk production more than energy. Similarly, Fandrejiwski et al. (1998) reported that yields were more dependent on intake of protein than energy. They estimated the daily maintenance requirement for protein to be 0.37 g/kg$^{0.75}$ and the efficiency of conversion of body protein into milk 0.9 (1/1.1). Similarly, using a continuous-time Markov model, LaBore et al. (1988) showed that increasing non-protein energy intake increased milk yield slightly, whereas increased protein intake resulted in large increases in milk yield but at the expense of depleting body energy.

However, Royal and Jeffery (1972) were of a different opinion. They observed a significant linear correlation between dry-matter intake of supplement and milk production, which indicated that milk production was limited more by energy than protein supply (see section 4.3.2. for a more detailed review of protein–energy relationship).

Mechanistic models

Lactation curves

The complexity of milk production implies that simple empirical equations will be inadequate to allow prediction of responses that are of acceptable accuracy in relation to whole animal performance. Beever et al. (1991) reviewed the mechanistic model of lactation curve of Neal and Thornley (1983) who found the model useful in describing the lactation curve but that it did not take account of the responses to changes in nutrient inputs.

Response to nutrients

Mechanistic models offer an alternative and potentially more powerful approach for predicting lactational responses to nutritional inputs (Sutton 1989). The composition of milk can be varied depending on the composition of the ME provided by a feed. For example, milk fat yield was depressed in response to feeding starchy compared with fibrous concentrates (Sutton et al. 1985).

Some of the most comprehensive mechanistic models developed for dairy cow metabolism are described in three major works of Baldwin et al. (1987a, b, c) which was based on principles developed by France et al. (1982).

Our understanding of the importance of nutrient balance comes from metabolism models. Assis et al. (1998) showed that by simulating various combinations of nutrient supply, it was possible to predict milk production and identify the limiting factors. Gill and Beever (1988) argued that although in the immediate future implementing the knowledge gained from use of some mechanistic models may improve the applicability of existing systems, a long term solution will rely on a more mechanistic approach based on metabolism of individual nutrients. Further research is required not only to predict milk yield in undernourished animals but also to optimise combinations of nutrients for better output of yield than currently produced by these animals in the tropics.

Kerr et al. (1991) demonstrated another importance of modelling. They used a time series modelling approach to quantify the effect of introducing maize silage into a tropical farming system. Based on trends before introduction of silage they were able to predict the increase in milk production due to the new feed. This approach emphasises the contribution of modelling in evaluating new technologies without incurring large costs and time in setting up feeding trials.

Systems models

Richardson et al. (1998) developed a dynamic systems model that predicts the effects of different management strategies on producing milk, meat and surplus animals for specific sites. The model can be adapted to any region by supplying information on weather, soils, forage production, diet selection of animals, food intake, digestion and animal metabolism. The model contains several sub-models, which can be modified depending on the region. As new information comes out, it can be incorporated and the model modified to account for the difference.

A simulation model developed by Witten and Richardson (1998) predicts change of body composition and ME required for maintenance. The model predicted that the ME required for maintenance changed over time in response to previous intake. The model can help in management decision taking by predicting the effects of undernutrition on the probability of survival so as to show the farmer the level of minimum input required to avoid losses. It can also predict the time required for cattle to reach the weight and physiological condition at which they could be used for draft or meat.

Based on model simulations, several management strategies have been proposed to ameliorate the effects of undernutrition particularly during the dry season. Thornton (1989) using an energy-based animal production model (Thornton 1988), recommended that the detrimental effects of undernutrition due to limitation of energy in the dry season on long-term herd stability and productivity could be avoided to some extent by a nine-month breeding season such that no calves were suckled during this time, and by removing milk from the herd during the wet season only. Richardson et al. (1998) recommended destocking during the dry season, the amount depending on the carrying capacity of the rangeland to avoid severe stock losses. Hary et al. (1996) citing an example from Kenya strongly argues that destocking policy ignores the spatial and temporal variability in primary biomass production and the effect of spatial and temporal fluctuations in forage quality on animal production. Contrasting ideas on carrying capacity and degradation of rangelands could be reconciled using a systems model that simulates both crop growth (e.g. Crout et al. 1997) and animal production.

Simulation models of whole animal production systems can help to prioritise the challenges faced in a particular system. For example, The Sheep and Goat Simulation Model when calibrated to conditions in Tanzania was able to identify seasonal changes in live weight due to helminth and improvements in feeding systems were likely to have had marginal effects (Hendy and Carles 1993).

Conclusion on modelling

As demonstrated above, empirical models and feed evaluation systems although useful for a given set of environmental conditions, are inadequate to gain insight into the processes involved and the results are not easily transferable. In contrast, France et al. (1998) have demonstrated the increasing relevance of biomathematical modelling in ruminant nutrition. Taking examples from their earlier work, the authors showed the use of mechanistic modelling at the organisational levels of the component process (e.g. rate of passage of food component in the rumen), the whole organ (e.g. rumen), and the whole organism (e.g. nutrient use by dairy cow).

Nutrition models for ruminants currently available are useful tools for investigating management options but lack of user-friendly interfaces will limit their application (Walker 1993) especially in the tropics. In any models developed in the future, particular attention should be given to the ease of use of such models by research scientists, extension workers and possibly educated farmers. Currently, efforts should concentrate on producing models, which are:

- based on sound mathematical principles
- containing as few parameter input as possible without reducing the efficiency of the model
- windows based and menu driven for user friendliness and
- having an output format compatible with widely used word processors and spreadsheets for analysis of the results.

Schmidely (1996) after comparing some mechanistic models concluded that mechanistic models must be developed more to identify fields of insufficient knowledge, to identify key interactions of metabolism with the aim of manipulating the metabolism for more efficient production. To quote from Danfaer (1991), 'All knowledge comes from experiments and observations. Knowledge can be used to make models. Good models can be used to improve the design and interpretation of new experiments. Better experiments and better interpretation will increase knowledge. And increased knowledge is a basis for better models. Hence, experimentation and modelling in animal science can support each other by a self-increasing process. This could lead to more efficient use of research funds and eventually to improvements in animal production'.

It is clear that a more mechanistic approach to modelling is required to understand the underlying animal metabolism principles and to integrate new research results for better prediction and management decision-making.

Nutrition models

Although there are useful nutrition models, the major factor limiting their uptake is their difficulty of use. As a result, instead of developing new models, it is recommended that work should concentrate on adaptation, better interface and evaluation of existing models. Dijkstra et al. (1996a) developed the mechanistic model of digestion and absorption of nutrients in cattle. This work can be taken forward by co-operation of scientists from ILRI and perhaps the original modellers. A research proposal could be outlined along the following lines (France, personal communication):

- front-ending the model (making it user friendly by perhaps using visual basic modelling)
- adapt the sugarcane-based diet into other primary forages to be determined through discussions with ILRI and perhaps other national agricultural research systems (NARS) staff
- parameterise the model for the Indian subcontinent especially in relation to buffaloes

- adapt the model to other ruminants such as goats to investigate nutritional requirements and suggest ways of improving animal production.

Energy–protein relationships

Modelling could be effectively used to gain insight into nutrient balance to improve animal production. For example, there is no clear guideline as to the energy and protein balance required for various stages of ruminant growth and production levels. Mechanistic models could help to identify:

- the energy–protein balance required and make recommendations which should be verified by experiments
- the extent to which tissue gain could be achieved with no exogenous energy in the presence of endogenous energy such as fat reserves in early dry season
- the type of data required when feed evaluations are planned so that they can be used in various types of models.

If energy or protein intake is below maintenance requirement, there is a need to accurately determine the composition of nutrients needed to be ingested with feed (fat, protein, glucose). A modelling approach together with experimental work might be needed here.

Growth models

Modelling work on growth of ruminants need not start from scratch as mechanistic models dealing with nutrient absorption and its effect on carcass weight and composition exist. Gill et al. (1984) developed the models that describe the metabolism of absorbed nutrients in a growing sheep and France et al. (1987) have a potential of being modified to study the effect of varying nutrient composition and period of undernutrition in smallholder production systems in the tropics. Therefore, research funds can be efficiently used by building up on knowledge described in the above models and experiments should be targeted to collect information on the effect of severe undernutrition during dry season and the subsequent availability of pasture during the wet season.

Milk productivity models

Milk is an important commodity in smallholder farming systems and the main source of nutrition particularly to children. Yield prediction and composition of milk is therefore of paramount importance. As in growth models, dynamic milk productivity models also exist. Baldwin et al. (1987a, b, c), for instance, developed the models for dairy cows. Due to their mechanistic nature, the models could be adopted for tropical smallholder farming systems with additional experiments designed to produce data that would help to modify the parameters for accurate prediction.

Nutrient cycling

Besides modelling the effects of undernutrition at the animal level, attention should also be given to modelling nutrient cycling in the whole farming system. Studies could be carried out to:

- investigate the effect of limited grazing field (taken for crops) on animal production
- study the continuous depletion of minerals from the soil and its effect on the mineral status of the crops and the animal.

This will eventually ensure translating the effects of undernourished animals to the level of the farming system.

General recommendations

From the review, a number of areas for further research have been identified. Because much of the available literature comes from temperate environments in the developed world, research for the tropics should include both large and small milk producing ruminants.

1. In the United Kingdom, evaluations based on traditional energy and protein systems have been widely replaced by more sophisticated systems, such as that for metabolisable energy and metabolisable protein (e.g. ARC 1980; AFRC 1993), which consider metabolisable and fermentable energy together with protein supply (microbial and true), to the duodenum. Nutritional needs of the goat have been studied (AFRC 1998). However, these systems may not be suitable for extremely low protein–low energy feeds and the animal genotypes found in the tropics. The situation is exacerbated by feed shortages, caused both by low rainfall, long dry seasons and land shortage. There remains a lack of primary experimental data on which to develop specific recommendations (e.g. responses to nutrients) for ruminants in the tropics.
2. Lifetime performance of livestock is a key indicator of success for the livestock producer. The implications of underfeeding at all stages, from prenatal to the end of the animals productive life, need understanding. There is little information in the literature on this topic, and what there is does not relate to the milk-producing ruminants of the tropics.
3. Reproduction is an integral part of dairy production and its efficiency is affected by nutrition and heat stress. The nutritional requirements to ensure both the first and subsequent conceptions, and supplying the needs of the suckling offspring need determining.
4. The causes for the lack of response in milk production (and/or growth) to supplementary feeds and methods to increase response require investigation.
5. Developing feeding responses specifically for the tropics, with emphasis on the following aspects:
    - Energy metabolism in underfed animals: maintenance, survival, carcass composition
    - Nutrient response in females, both in lactation and the dry period
    - Mineral requirements.

6. Feed responses need also to be considered in comparisons between indigenous and exotic breeds. Emphasis is needed on crossbreeding and the contribution of heterosis beyond the first generation. Dual-purpose (lactating and draft) animals, with emphasis on the degree of stress to be applied (nutritional and environmental).
7. The nutritional characteristics of feeds and their likely contribution to rumen fermentation and their synergism with other components of the diet. Because of the wide diversity of feed resources in the tropics, simple procedures to characterise feeds available locally, and regionally are required. Slow release urea compounds should be tested.
8. The major feed resources in the tropics are forages (good in the rains; poor in the dry season) and cereal crop residues. To optimise production from these, more information is needed on:
    - Total intake and selectivity as affected by: components of the grazing, amount and condition of that available.
    - Methods of conservation to avoid wastage, in times of plenty, and deterioration of that to be carried over to the dry season.
    - Research on crop residues should aim to reduce the indigestible roughage portion of the diet. Three areas for improvement are: improved handling and storage (conservation, especially of 'green' residues, and climatic differences must be allowed for); the use of urine as an improvement agent; the use of enzymes.
    - Many of the food plants occurring in the tropics are tanninferous. The nature of the tannins is generally unknown, as is their effect on the animal (possibly determined by the level of feeding). The helpful or harmful effects of tannins needs determining in field based studies.

Topics having a bearing on the general recommendations

- The role of water in intake and digestive processes. The water requirements of working animals need particular attention.
- Studies on heat fall into two categories which are related: the first concerns the direct effects of heat stress, as seen in nutritional efficiency and production; the second concerns the thermoregultory processes within the animal.
- Health and nutrition linkages, with emphasis on the total nutrient resource cost of parasites and diseases.
- For sustainability of the system, environmental factors must be considered.

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Case studies of undernutrition of ruminant livestock in the tropics

Undernutrition of dairy cattle in smallholder production systems in East Africa

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Summary

Variations in availability and nutritional quality of feed resources in the tropics affect cattle production under smallholder production systems. This results in undernutrition of cattle because of fluctuations in feed and nutrient supply. The term undernutrition is very complex and not clearly understood. The end products from animal production in the forms of body growth, milk yield, reproduction and traction power are expressed as a result of the influence of undernutrition. The mechanisms involved in physiological changes need to be understood. In this paper, attempt is made to define undernutrition in cattle, how and when it occurs and its causes and manifestations. The focus is on improving milk and meat production and on increasing the efficiency of use of traction animals. Studies undertaken by the International Livestock Research Institute (ILRI) on improving milk production under smallholder production systems have focused on feed resources development, feeding systems, improving feed use and on management strategies for different classes of dairy animals. Strategies to improve milk production in the tropics, managing oxen to improve work performance and the effects of level of feeding on carcass composition are explained based on studies undertaken in East Africa. ILRI's work on undernutrition in ruminants in crop–livestock systems of the sub-humid zone of West Africa and for the semi-arid (Sahel) zone are also presented.

What is undernutrition?

Nutrition involves various chemical reactions and physiological processes, which transform nutrients into body tissues and activities. These embrace ingesting, digesting and absorbing of various nutrients, their transport to body cells, and the removal of unusable elements and waste products of metabolism (Maynard et al. 1981; McDonald et al. 1988). From the definition, therefore, it follows that nutrition can be inadequate, either through being insufficient (undernutrition) or inappropriately balanced in relation to the animal's needs (malnutrition). Naturally, it is possible to have a combination of the two with an animal receiving too few nutrients in total and those nutrients also being incorrectly balanced (Oldham et al. 1993). Thus, undernutrition could be defined as the lack, shortage or imbalance of nutrients that will lead to the deviation from the normal physiological and metabolic processes resulting in poor animal performance. Undernutrition occurs when a diet deficient in one or more food constituents (specific undernutrition) is consumed or when insufficient quantities of an otherwise adequate diet are consumed (general undernutrition). The adequacy of a diet, i.e. the extent to which it meets the nutrient requirements is defined in terms of the response of the consumer as manifested in growth, milk production, health, activity etc. (Saris et al. 1998; Waterlow 1992). In short, undernutrition can also be defined as insufficient eating leading to loss of body weight and/or to a decrease in a productive process (growth, milk, reproduction) (Forbes 1995).

Where is it prevalent?

Undernutrition is prevalent in smallholdings in developing countries where animals experience a fluctuating supply of nutrients (Orskov and Chowdhury 1990). Undernutrition has also been reported in the developed countries of the West. In the well-developed animal feeding systems in temperate countries, undernutrition could be an economic strategy adopted by farmers to minimise cost of feeding. It can also arise as a physiological situation in high-producing dairy cows (Grimaud et al. 1998) where physical limitation (capacity) of the stomach limits the quantity of feed intake and as such, extractable nutrients to meet nutrient demands. Similarly, physical limitation is also the principal cause of undernutrition noticed in pregnant females, especially cattle. However, the duration and degree of undernutrition in temperate countries is to a much lesser period and severity than is commonly encountered in the developing countries of the tropics and sub-tropics.

What causes it?

Feeds available for smallholders in tropical developing countries are generally deficient in most nutrients and have low digestibility, which leads to low intake due to limited rumen capacity. The problem gets worse when other abdominal organs are competing for space (uterus or fat). Fat cows eat less than thinner ones in early lactation and cows fed at maintenance during the dry period ate 11% more during the first 16 weeks of lactation than those fed at 1.8 of maintenance (Forbes 1995). When given a high energy food (13 MJ/kg DM) thin cows ate more than fat cows and produced the same amount of milk but when a poor quality food (9.8 MJ/kg DM) of the same CP content (180 g/kg DM) was given, intake was not affected by body condition with the result that thin cows produced significantly less milk (Forbes 1995). Heifers are particularly susceptible to low intake of poor foods at the onset of lactation (Bines 1985). During grazing, intake can also be inadequate if amount of herbage available for grazing is very sparse and each mouthful is small meaning that there is not enough time in the day for the animal to eat enough (Osuji 1974).

Additionally animals are constantly subjected to fluctuating supply of poor quality feeds. Fluctuation is a result of seasonality and small area of arable land per farm, meaning that no land is available to be devoted to feed production but animals depend on communal grazing (marginal land, native pastures, bottom lands which are decreasing), and crop residues. Seasonality of rainfall is a crucial element of climate and therefore controls vegetation growth throughout the tropics and sub-tropics. The highly seasonal rainfall is concentrated within a short period, whereas, the amount and timing of the rain are important factors. From observations in the last three decades, the present reality is that rainfall patterns have shown shorter durations, greater inconsistencies and lesser volumes with incidence of recurring droughts. Thus, the biggest management problem facing stockowners in many tropical and sub-tropical parts of the world is the provision of adequate feed to ruminants during the long dry season when forages deteriorate and become low in quality on account of the increased cellulose and lignin contents and a low level of protein. Animals on range are particularly vulnerable especially when the supply of grazing is further reduced by periodic droughts (Orskov and Chowdhury 1990; Olafsson and Gudmundsson 1993).

How is it manifested?

Animals subjected to undernutrition have several physiological mechanisms to cope with it. The main evidence of undernutrition is loss in body weight and condition when animals are withdrawing energy from their tissues. This also results in shifts in the relative proportions of the various organs and tissues and in the chemical composition of the body. In the first place, body fat will be depleted resulting in increases in blood non-esterified fatty acids (NEFA).

Maintenance requirements of undernourished animals can be reduced to a level that approaches their basal metabolic rate thus providing a mechanism that assists their survival in times of poor nutrition (Ryan 1990). An example of these mechanisms is the changes observed in underfed ewes when in the portal-drained viscera and liver, oxygen (O_2) extraction rates decreased, leading to 34 and 38% drops in O_2 consumption with underfeeding, respectively. Consequently, the portal-drained viscera, liver and carcass were responsible for 39, 32 and 5%, respectively, of the drop in whole-animal O_2 consumption with underfeeding (Ortigues and Durand 1995). Also, increased uptake of amino-acids from portal drained viscera has been demonstrated in semi-fasted ewes (Nozière et al. 1999).

In general, decreased intake increases digestibility when diet composition does not change. However, in case of feeding levels below maintenance, results are not convergent; in some cases, digestibility has not changed (Grimaud and Doreau 1995), has increased (Kabré et al. 1995; Michaelet-Doreau and Doreau 1999) or decreased (Gingins et al. 1980; Ortigues and Vermorel 1996; Grimaud et al. 1998).

In a dairy animal, undernutrition manifests itself in reduced milk production and changes in the composition of milk. Undernutrition in the dairy cow affects the way nutrients are used. Depending on the extent of undernutrition the lactating cow may breakdown its tissues to support current production. Zebu cows are said to reserve their milk for their calves when subjected to nutritional stress. They also divert nutrients to tissue deposition rather than support current milk production. Under these situations, what happens with realimentation is of interest.

Realimentation is a state of energy supply widely covering estimated requirements after a period of undernutrition. However, lactating animals have a very limited opportunity to later compensate the depression in milk yield caused by deficient energy and/or protein (Kirchgessner et al. 1986; Kreutzer 1998). Instead, in growing animals compensatory growth has been demonstrated in many studies (though complete compensation has not been demonstrated in cattle) (Ryan 1990). However, animals restricted prenatally, immediately after birth, and close to maturity are unlikely to compensate (Ryan 1990).

Tropical areas are characterised by restricted water supplies and a low N-content of available grazing. Ruminants are well adapted to semi-arid conditions, and can tolerate restricted water intake (as little as 50% of *ad libitum* intake). For example, early studies showed that sheep might withstand prolonged periods of restricted watering, i.e. every second day, without adversely affecting feed intake, or growth (Clark and Quin 1949a, b). In addition, they are able to maintain whole-body N-balance at a protein intake of as little as 7% crude protein (CP). Restricting the CP content of the diet fed to cattle in East Africa not only reduced the amount of nitrogen excreted in the urine as urea, but restricting the water intake further reduced the loss of nitrogen (Livingston et al. 1962). Restricting water intake of sheep does conserve N-retention when the N intake is <8 g N/day. The mechanism does not involve the kidney or the rate of passage through the digestive tract. Possible mechanisms may involve N recycling in the rumen or large intestine.

Work has continued on protein nutrition when energy intake is fluctuating. This has led to a greater understanding of the ability of the animals to use body fat, not only for survival during periods of limited exogenous energy, but also for growth when protein supply allowed a positive protein balance. Both lambs and heifers have been shown in practice to be able to gain weight in substantial negative energy balance. With steers on intragastric infusion and provided enough protein is supplied, a live weight gain calculated from N balance of well in excess of 1 kg/day has been obtained with no exogenous energy input. It has also been shown that the response to increasing protein supply is not altered substantially by semicutaneous infusion of exogenous energy-yielding nutrients. It would seem that within limits the animals could tolerate wide fluctuations in exogenous energy supply and maintain growth provided fat stores are available and sufficient protein is supplied (Orskov and Chowdhury 1990).

Undernutrition is thus a pervasive problem in most tropical and sub-tropical developing countries. The aim of ILRI's work is to increase productivity of smallholder farms, as most of the animals are indigenous and of zebu breeds. There are several options to increase the output of milk and meat. ILRI's research has tried to focus on these options including the causes and consequences of undernutrition and how best to manage these.

ILRI's undernutrition related research

ILRI has been involved in development-oriented research aimed at increasing productivity of ruminants kept by smallholders. The dominant ruminant genotypes are the indigenous breeds. This research effort, among others, has focused on improving milk and meat production and on increasing the efficiency of use of traction animals. Studies on improving milk production under smallholder production systems have focused on feed resources development, feeding systems, improving feed use and on management strategies for different classes of dairy animals. This paper focuses on undernutrition in dairy cattle in East Africa. ILRI's work on undernutrition in ruminants in crop–livestock systems are presented in this workshop by Larbi for the sub-humid zone of West Africa and by Fernández-Rivera for the semi-arid zone (Sahel).

It is recognised that in many tropical countries the bulk of the milk produced is from the indigenous cows, which are predominantly zebu breeds. In Ethiopia, for example, about 99% of the milk is produced from the indigenous cows. The majority of the indigenous animals are held in smallholdings. The smallholders use these indigenous cattle breeds for multiple purposes. They are used for milk and meat production and for traction purposes and as such are not specialised breeds for any single production trait. Zebu cattle have been selected, over millennia, for adaptive rather than productive traits that allow them survive under harsh and unpredictable environmental conditions (Bondoc et al. 1989). These adaptive qualities are associated with survival traits against major constraints such as diseases, heat, ability to cope with water shortage/deprivation and survival on poor quality diets. As a result, the productivity of these animals in terms of growth, meat and milk production, reproduction and draft are lower than those of the improved European breeds and these low production traits are strategies to ensure survival.

Natural selection ensures that the amount of milk produced from the indigenous cows is basically limited to supporting the calf. Lactation length is limited to approximately five to six months, which corresponds to the normal weaning age of calves under natural management systems. Milk let down is better initiated in the presence of the calf and cows are usually milked after the calf has sucked for a few minutes to stimulate let down. Milking is usually accomplished with the calf by the cow side.

Attempts to improve milk production from indigenous cattle through better nutritional management have not been successful (Olaluku and Oyenuga 1974; Khalili et al. 1992; Tegegne et al. 1994; Osuji et al. 1995a). Studies at ILRI Debre Zeit Research Station with Boran cattle showed that supplementation with wheat middlings (DM = 893 g/kg and CP = 222 g/kg) at a rate of 5 kg/head per day increased milk yield from 2.7 to 3.9 kg (Tegegne et al. 1994), indicating that for every kg of supplement there was a 0.24 kg increase in milk yield. This increase in milk production through additional nutritional intervention may not be economically justifiable under market-oriented smallholder milk production systems. For example, considering the current price of wheat middlings (US$ 8.75/100 kg) and fluid milk (US$ 0.21/kg) in Debre Zeit, the input–output ratio would mean a feed cost of US$ 0.37 per litre of milk (which generated only US$ 0.21), incurring a loss of US$ 0.16 for the additional litre of milk produced. However, the supplemented cows had better body condition indicating more fat deposition that could be mobilised during periods of feed shortage. A similar study with Boran cows supplemented with molasses and increasing levels of cottonseed cake showed increases of 200 g more milk per day with 1.85 kg molasses. When cottonseed cake was increased by 0.9 kg per day, milk yield increased from 2.96 to 3.32 kg per day (Table 1) (Osuji et al. 1995a).

Table 1. *Milk yield and live weight in* B. indicus *cows given wheat–oat straw* ad libitum *with (M+) or without (M–) molasses plus increasing levels of cottonseed cake (CSC).*

Treatments (kg DM/day)			Live weight	
Molasses (M+)	CSC	Mean yield (kg/day)	Mean (kg)	Change (kg/day)
1.85	1.35	3.07	287	0.11
1.85	1.80	3.38	285	0.26
1.85	2.25	3.34	288	0.78
Molasses (M–)				
0	1.35	2.84	291	0.03
0	1.80	3.06	289	0.09
0	2.25	3.29	288	0.15
SEM		0.125	1.4	0.157
CSC				
Linear		**	ns	*
Quadratic		ns	ns	ns
Molasses		*	*	*

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns = not significant.
Source: Osuji et al. (1995a).

Major productive characteristics of the indigenous zebu cattle as compared to crossbred/exotic breeds are slower growth rate, slower sexual development and maturity, late age at first calving, lower daily and lactation milk yields, shorter lactation length and longer calving interval. The combined effect is lower lifetime productivity (ILCA 1993). The dominant strategies to improving milk production in many tropical and sub-tropical countries have been through crossbreeding the indigenous cows with exotic dairy breeds even though some selection and better management are in progress. However, results of these efforts show very little progress and as such the per capita milk consumption in these countries have not matched projections (Delgado et al. 1999).

Strategies to improve milk production

Indigenous cows

Selection and breeding

Indigenous cattle have been naturally selected for adaptive, rather than for productive traits. Selection takes a long time and requires sustained effort to make substantial genetic progress and impact on productivity. However, due to the high genetic variability among these indigenous animals, there is a potential to select for productive traits. There are some individual animals with relatively high milk production. Heritability and repeatability estimates for most productive traits in the indigenous cattle breeds are low to moderate (Bondoc et al. 1989). Given the recent advances in reproductive biotechnology, there is a potential to select and breed indigenous breeds for improved milk production. Based on this a number of efforts are being made to improve milk production from the indigenous zebu breeds in many tropical countries. In some countries, sizeable and commendable selection and breeding programmes have been carried out with reasonable improvements in milk production. The possibility of crossbreeding between the various zebu breeds/genotypes with the objective of improving milk production still exists, as demonstrated by developing the Jamaica Hope, and has not been adequately and exhaustively explored.

Improving daily milk yield and lactation length

Lactation curve, peak milk yield and persistency of zebu cows are not similar to that of the improved exotic dairy breeds (Figure 1). Improvement in daily milk yield could be considered as one of the strategies to increase the overall milk output of cows, i.e. assuming that persistency and lactation length are improved. This could be achieved through nutritional management interventions during the most critical periods of the lactation period and life cycle. Improvements in nutritional management during the later quarter of pregnancy and during the early lactation period could increase peak milk yield, improve persistency and increase lactation length (Figure 2) (Tegegne et al. 1994). However, these improvements should not be expected to be dramatic, as the milk yield response of these breeds is small (Table 1) (Osuji et al. 1995a). The most important impact from such an effort could be through increase in milk yield from a large number of animals. The economics of such nutritional intervention, however, needs to be carefully considered. Pasture improvement, integrating forage legumes into the farming systems (Crosse et al. 1999a), backyard fodder development, enhanced and strategic use of multi-purpose trees and agro-industrial by-products could provide cheap feed resources to smallholder farmers to effectively improve the nutrition of their animals. Such nutritional interventions will undoubtedly also have a positive influence on the milk production and reproductive efficiency of the indigenous cows (Crosse et al. 1999a, b; Mpwaire 1999).

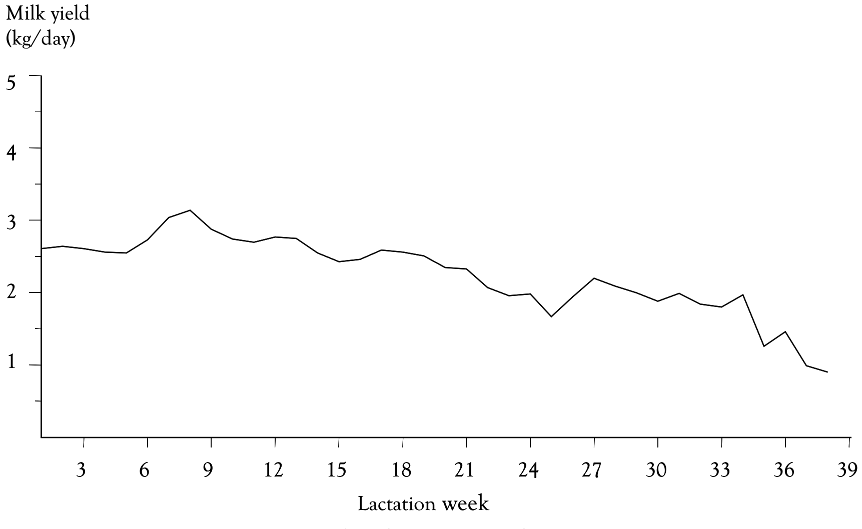


Figure 1. *Lactation curve of Boran cows at ILRI's Debre Zeit Research Station.*

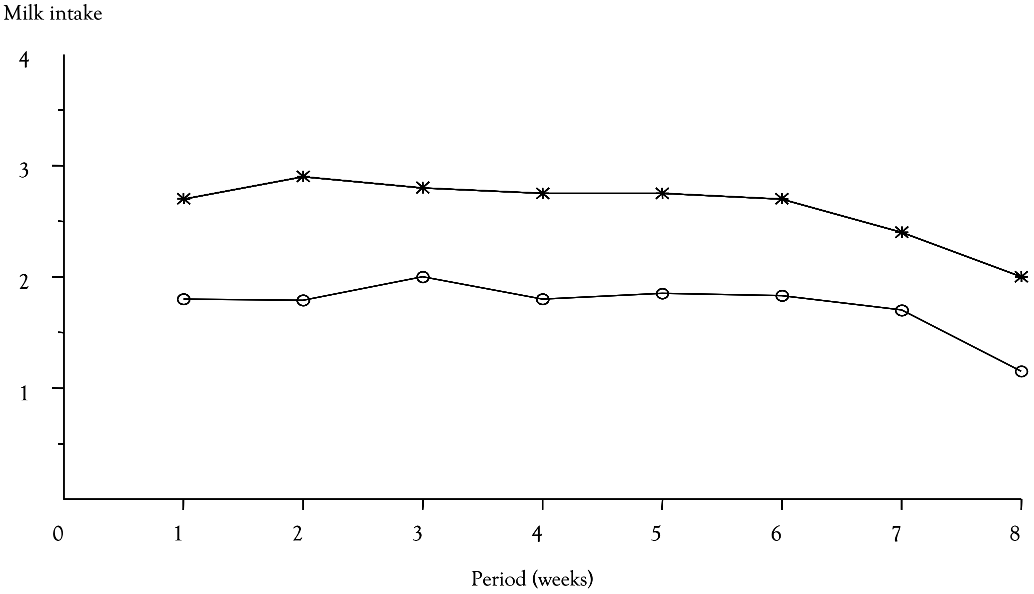


Figure 2. *Average daily milk intake (litre/day) by Boran × Friesian calves which sucked unsupplemented (o) or supplemented (✱) Boran dams and weaned at age of 8 weeks.*

Increasing the number of lactations

As indicated above, nutritional intervention at critical periods of the reproductive cycle of the animals will enhance reproductive efficiency. Improvements in reproductive efficiency will have a direct bearing on milk production through improvements in the number of lactations over the lifetime of animals as observed in crossbred heifers at the ILRI Debre Zeit Research Station (ILCA 1993). This could be achieved through manipulating early body growth and sexual maturity of heifers (Tegegne et al. 1992), reducing calving intervals, improving fertility and reducing young mortality (Entwistle 1983).

Reducing age at first calving: Slow body growth, lower weaning weights, delayed reproductive development and sexual maturity have been identified as the characteristics of young zebu cattle. Heifers attain puberty not earlier than four years of age and calve for the first time at about five years of age. Calving rate in heifers is also lower than in cows. A calving rate of 40 to 45% in heifers bred for the first time is common (Tegegne et al. 1993). Reducing the age at first calving and improving calving rate in heifers is one of the challenges in improving lifetime productivity among the indigenous cattle breeds.

A number of studies have demonstrated that proper nutritional management of heifers enhances growth rate, reduces age at puberty, increases conception rate, promotes mammary development and decreases the age at first calving. If conception rate is improved and the age at first calving is reduced, then the animal gets into her productive life relatively earlier. Smallholder farmers can start extracting milk and generating income from the animal at a relatively younger age. The cost of feed and management in heifer rearing is substantial, and it increases as the unproductive life (age at first calving) of the animal increases. For example, in improved Boran heifers under grazing management, dietary supplementation restricted to the dry season only resulted in a 52% pregnancy rate at 18 months of age (Tegegne 1989). Strategies to develop feeding and management systems to improve heifer fertility and decrease the age at first calving should be an integral part of the effort to increase milk production.

Reducing calving intervals: The post-partum period is the most critical period in the reproductive cycle of a cow. Initiating lactation increases the demand for nutrients. The animal shifts its metabolism towards the supply of nutrient precursors needed for increased milk production. This is particularly important in first calf heifers where there is an increased concomitant demand for nutrients for milk production, continued body growth and initiation of ovarian functions. There is also a tendency for an inverse relationship between age at first calving and post-partum anoestrus interval in heifers, and this is particularly true in underfed animals. When nutrients are not adequate or in short supply, reproduction suffers until the animal ensures adequate body reserves in the form of fat. The priority for zebu cows is to produce enough amounts of milk for the calf.

Suckling is one of the major factors, which contributes to extended post-partum interval in zebu cows. The suckling stimulus and the presence of the calf both have a direct effect on the endocrine functions of the cows and affect the resumption of post-partum ovarian functions. Suckling management and weaning strategies such as temporary weaning, early weaning, restricted suckling and partial suckling have been shown to reduce the post-partum anoestrus interval and improve fertility (Tegegne 1989).

Inadequate nutrition or nutritional imbalances and heat stress increases embryonic mortality and foetal losses in both heifers and cows. The ratio between protein and energy supply is an important factor when feeding heifers and cows to optimise reproductive efficiency. High protein diets increase urea concentrations in the uterus and have detrimental effect on embryonic survival. Similarly, low energy diets have direct effect on hormonal synthesis and balance and affect ovarian functions. Also, heat stress increases uterine temperatures and has a direct effect on hormonal and electrolyte balance and affect fertility and embryonic survival. Moreover, heat stress affects feed intake and indirectly influences fertility.

Reducing calf mortality: Low reproductive rates and high calf mortality are the major causes of reproductive wastage, which have a direct bearing on culling and replacement rates and on genetic improvement and progress. Calf mortality could be as high as 50% in many tropical countries. This is mainly attributed to diseases and poor feeding and management of calves. A study on calf management strategies at ILRI Debre Zeit Research Station (Khalili et al. 1992; ILCA 1993; Tegegne et al. 1994; Osuji et al. 1995b) showed that zebu and crossbred calves could be provided with 134 kg of whole milk and successfully weaned at 57 days of age without any mortality and without affecting subsequent body growth and development (Tables 2 and 3).

Proper feeding and hygiene management of calves are important factors that affect calf survival and growth rate. Under smallholder conditions, early weaning of calves also has an added advantage in increasing the total amount of saleable milk from cows, contributes to the early resumption of ovarian functions and improves fertility.

Table 2. *Growth performance of Boran × Friesian* F_1 *crossbred calves.*

	Bucket-fed		Suckled with dams			
			Supplemented		Unsupplemented	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Weight (kg) at						
Birth	25^a	0.7	25^a	1	25^a	1
Weaning	37^b	1.8	51^b	2.6	44^c	2.6
3 months	45^a	2.2	58^b	2.9	50^a	2.9
8 months	103^a	4.3	118^a	5.6	113^a	5.9
Average daily gain (g/day)						
Birth to weaning	215^a	29	477^b	41	346^c	41
Weaning to 3 months	436^a	42	432^a	56	409^a	56
Weaning to 8 months	376^a	23	379^a	30	429^a	32

Figures followed by different superscripts differ significantly ($P < 0.05$).
Source: Osuji et al. (1995a).

Table 3. *Effect of levels of milk and types of housing on live weight (kg), average daily gain (g/day), weaning (days), and weaning weight (kg) of zebu calves.*

	Treatments				
Litres of milk	2	2	3	3	SEM
Housing	Barn	Hut	Barn	Hut	
Live weight (kg)					
Week 1	22.1	22.0	20.9	23.5	0.93
2	22.9	23.2	23.6	25.8	0.99
3	23.9	24.0	24.8	27.3	0.8
4	24.8	24.6	25.9	28.9	0.93
5	25.5	25.7	26.5	30.7	0.95
6	26.3	26.6	27.6	32.2	1.16
7	27.2	27.7	28.4	33.6	1.27
8	28.6	29.0	29.2	35.8	1.54
9	30.2	30.0	30.8	37.3	1.77
10	31.0	31.0	31.8	39.2	1.93
11	32.2	32.3	33.2	41.2	2.16
12	32.4	33.4	34.3	41.7	2.18
Birth weight (kg)	21.8	22.3	20.9	23.3	0.94
Average daily gain (kg)					
By regression	137	144.0	162.0	237	29.9
By difference	127	142.0	170.0	225	25.6
Weaning (days)	77.1	78.4	78.1	76.4	1.95
Weaning weight (kg)	30.4	31.6	31.9	40.2	1.82

Source: Osuji et al. (1995b).

Crossbred and exotic animals

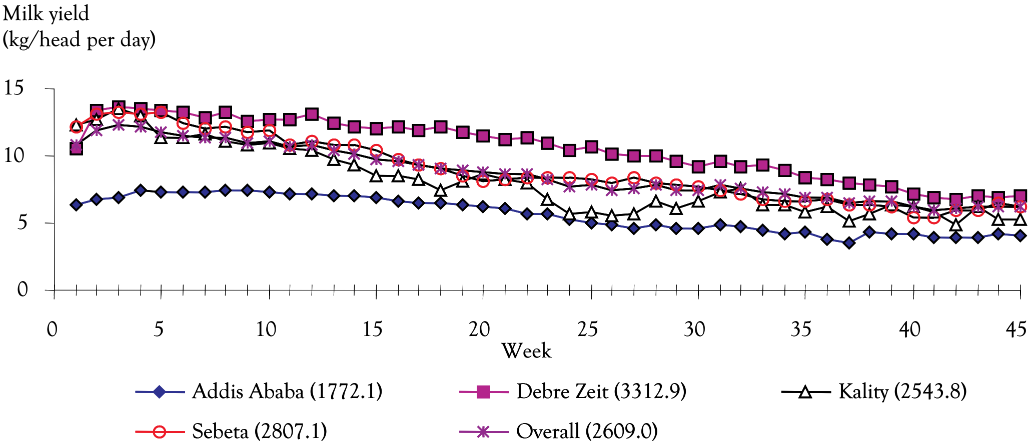
Genetic segregation in crossbreds

Crossbreeding indigenous zebu cows with exotic dairy type animals has been considered as one of the most promising avenues to improve milk production in many tropical countries. Although producing first generation crossbred animals (F_1) is relatively easy, variation in their genetic potential for milk production is quite large as a result of zebu and exotic genetic material inheritance. Selection and breeding among the F_1 generation has also been limited due to relatively few numbers of replacement animals and due to genetic segregation in subsequent generations. Sustained improvements in any crossbreeding programme could only be achieved if it is coupled with selection programmes.

One of the problems associated with any crossbreeding programme is in maintaining the heterosis. *Inter se* matings among F_1 animals results in producing F_2 generations and their milk production level is lower than the F_1 animals as a result of genetic segregation. Consequently, in any crossbreeding programme there is a tendency to upgrade F_1 animals to higher exotic blood level inheritance with an attempt to substantially increase milk production. The effect of increasing proportion of *Bos taurus* genes on milk yield, calving interval, lactation length and age at first calving have been well illustrated (Cunningham and Syrstad 1987). Upgraded animals have a higher demand for nutrition, have less disease tolerance and are usually beyond the management capacity of smallholder farmers. The relatively poor management of these animals affects their productive and reproductive performances. For example, in Ethiopia in an attempt to improve milk production in the highlands, government ranches produce crossbred heifers (F_1 zebu × Friesian) for distribution to smallholders after they have been bred. The calf *in utero* in the heifers is usually of 75% exotic inheritance. Survival of the high-grade calf is low.

Lactation curve, peak milk yield, persistency

The milk yield response and reproductive efficiency of crossbred and high-grade animals is highly variable depending on genetic composition and management conditions. Nutritional management affects initial milk yield, peak milk yield, the time interval to peak milk yield, persistency and lactation length. Results from an on-farm study on crossbred cows in urban and peri-urban dairy production systems in the Addis Ababa milk shed indicated differences in these traits as a direct reflection of difference in nutrition (Figure 3) (Yoseph 1999). Although there could be a confounding effect of genotype of animals to a certain extent, the results indicate the potential for improvement in milk production through strategic nutritional intervention. Khalili et al. (1992) demonstrated significant increases in milk yield of crossbred cows fed hay or oat–vetch hay and supplemented with increasing levels of concentrate (Table 4). A similar study at the ILRI Debre Zeit Research Station under a more controlled environment showed that supplementing graded levels of lablab hay to Boran × Friesian crossbred cows fed oats–vetch hay and maize lablab basal diets improved initial and peak milk yields and improved the persistency of milk production (Figure 4) (Mpairwe 1999).



Sources: On farm data and Yoseph (1999).

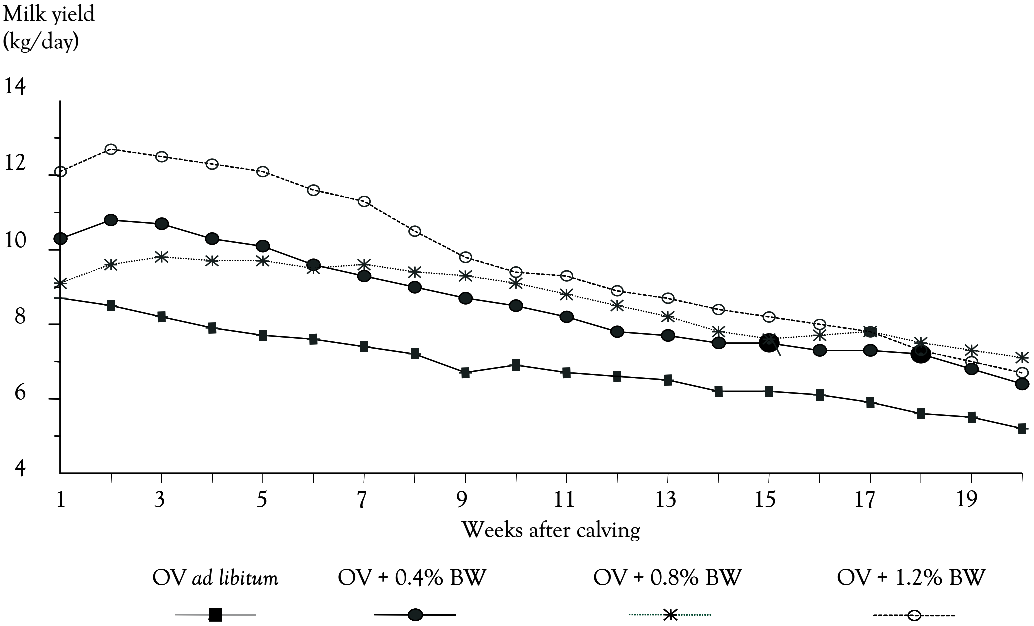
Figure 3. *Completed lactation milk yield of cows.*

Table 4. *Milk yield and composition in crossbred cows given grass hay or oat–vetch hay* ad libitum *with increasing levels of concentrate supplement.*

Treatment				
Forage (F)	Concentrate supplement (S)	Milk yield (kg/day)	Milk fat (g/kg)	Milk protein (g/kg)
Hay	0.0	4.14	40.6	25.2
	2.5	5.62	40.3	26.1
	5.0	6.78	40.1	26.9
Oat–vetch hay	0.0	5.54	37.9	27.0
	2.5	6.66	38.9	27.9
	5.0	8.07	40.0	27.5
s.e.		0.202	0.85	0.45
Significance[1]				
S (linear)		***		*
F		***	*	***

1. S (Quadratic) and F × S interactions were not significant ($P > 0.05$).
Source: Khalili et al. (1992).

Proper pre-partum nutritional management of dairy cows is essential to ensure that cows calve in good body condition. This body reserve is usually mobilised during the post-partum period to support milk production, especially in high producing cows. Adequate feeding during the post-partum period, therefore, becomes essential to minimise body fat mobilisation and to ensure commencing early ovarian activities without sacrificing milk yield. Under such circumstances, cows tend to commence lactation at higher levels, followed by higher peak levels and increased persistency throughout lactation. Moreover, cows breed and conceive early during the post-partum period resulting in shorter calving intervals. Cows managed in such a manner will have longer lifetime productivity. Other environmental factors such as heat stress, diseases etc. have substantial influence on the productive and reproductive performance of crossbred and exotic dairy animals kept under tropical conditions. Heat stress directly affects feed intake and interferes with reproductive functions. Diseases such as mastitis, lameness, reproductive disorders etc. are of major concern in developing sustainable dairy production systems in the tropics. Other aspects of reproductive management to improve milk production in crossbred and exotic dairy cows such as manipulating age at first calving (Table 5), reducing calving intervals, minimising calf mortality to increase replacement rates are similar to that of the zebu animals.



Source: Mpairwe (1999).

Figure 4. *Effect of graded levels of lablab hay supplementation on mean daily milk yield of crossbred cows fed* ad libitum *oats–vetch hay (OV) basal diet.*

Managing oxen to improve work performance

Oxen are extensively used for traction purposes in many tropical regions. Crop production in some countries, such as Ethiopia, almost totally depends on oxen power. One of the major problems of smallholder farmers associated with the use of oxen power are: availability of oxen at the right time of the year and the work efficiency of oxen. Different strategies could be developed to ensure availability of oxen to smallholders at the right time of the year. Nutritionally managing oxen plays a significant role in determining the working efficiency of oxen. However, most smallholders do not have enough feed for their oxen and whatever feed they have is of poor quality consisting principally of crop residues and native pastures. In addition, population pressure leading to decline in land available for livestock may lead to farmers not being able to maintain draft oxen to work for only 50–70 days in the year. This led ILRI and IAR (Ethiopian Institute for Agricultural Research, now the Ethiopian Agricultural Research Organization, EARO) to undertake work on the use of dairy cows for traction as this could benefit total farm output and incomes through increased milk production, making it unnecessary to feed draft oxen year round and maintain a follower herd to supply replacement oxen and thus reduce the pressure on land and limited feed resources (Gryseels and Anderson 1983; Gryseels and Goe 1984; Matthewman 1987; Barton 1991).

Table 5. *Productivity indices at 3.5 years of age in zebu × Friesian crossbred heifers reared with different management systems to attain pre-pubertal growth rates of either 150–200 (low) or 500–600 g/d (high).*

Variables	High	Low
Attained puberty (%)	100.0	100.0
Age of puberty (months)	22.7	22.7
Body weight at puberty (kg)	278.2	277.5
Reproduction		
Pregnant (%)	100.0	86.4
Age at 1st calving (months)	31.0	38.0
Calved (%)	91.0	59.0
Reconceived (%)[a]	40.0	7.7
2nd calved (%)[b]	25.0	0.0
Calf weight (kg)		
Birth	26.2	25.6
Milk production		
Completed lactation (%)[c]	40.0	7.7
Lactation length (days)[d]	318.0	279.0
Daily milk yield (litres)[e]	6.5	4.9
Total milk produced (litres)	12,008.2	3831.8
Average number of days in lactations	273.3	131.0

a. Average of those that have calved up to 3.5 years.
b. Average of those that have reconceived.
c. Average of those that have calved.
d. For cows with complete lactation.
e. Average for the first three months.
Source: ILCA (1993).

Studies by ILCA/ILRI on draft oxen have provided substantial information on draft power requirements, work output and effect of work and nutritional stress on animal performance and on the causes of fatigue. Additionally, strategies for the use of available feed resources for the dual-purpose use of oxen for draft and beef have been evaluated (Osuji and Capper 1992). Nutrients needed by work oxen to optimise compensatory growth responses after a period of work were estimated. Effects of supplementation, body condition and work levels on the feed intake, live weight gain, carcass characteristics and physiological changes of zebu draft animals were studied in several trials.

In a series of experiments undertaken at the ILRI Debre Zeit Research Station, the effect of supplementation and differential work stress on feed intake, body weight changes and carcass characteristics of zebu oxen were examined. In addition, the effect of different feeding strategies of draft oxen on compensatory growth during the post-work recovery period was also investigated (Table 6).

Table 6. *Work and feeding levels of zebu oxen during work and recovery periods.*

		Feeding level	
Treatment	Work level	Work period	Recovery period
1	Idle	*Ad libitum*	*Ad libitum*
2	Idle	0.8 × maintenance	*Ad libitum*
3	Work	*Ad libitum*	0.7 × *ad libitum*
4	Work	*Ad libitum*	0.8 × *ad libitum*
5	Work	*Ad libitum*	0.9 × *ad libitum*
6	Work	*Ad libitum*	1 × *ad libitum*

Effect of work on physiological responses and blood metabolites

Effect of work and feeding regime on physiological parameters (rectal and skin temperatures, respiration and sweating rates), live weight changes and energy expenditure in supplemented and non-supplemented zebu oxen assigned to two levels of work (idle and work) were estimated. Work comprised of walking for 5 hours a day. The experimental treatments are given in Table 7.

Table 7. *Feeding and work levels of zebu oxen fed teff straw supplemented with a concentrate mixture.*

Level of supplement	Work level
0	Idle
0	Walking 5 h/d
10 g/kg live weight	Walking 5 h/d

Supplement = 200 g/kg noug cake + 400 g/kg wheat middling + 400 g/kg wheat bran.

Work had marked effects on the concentrations of blood metabolites (glucose, lactate, NEFA and ß-HBA). Plasma glucose was greater in work/supplemented (WS) oxen than in work/non-supplemented (WNS) oxen. At the end of work and just before work started glucose level was much higher in WS than in the other two treatments (Table 8). Zerbini et al. (1995) and Matthewman (1990) found that plasma glucose concentration was affected by both energy intake and work output, while responses of NEFA, ß-hydroxy butyrate and lactate were more related to energy expenditure during working hours. Within 1 hr of start of work glucose level was increased by 19.1, 21.4 and 17.7% in WS, WNS and Idle/non-supplemented (INS) oxen, respectively. Levels of circulating NEFA increased sharply in walking oxen. Within the first hour of work, levels of circulating NEFA increased by 76.5 and 103.6% in WS and WNS oxen, respectively. NEFA did not decrease after the work task for WNS oxen. The pattern of changes in Beta hydroxy butyrate (ß-HBA) concentration during work mirrored that of glucose during the same period. The level of ß-HBA was higher for WNS oxen than INS oxen after 3 hr of work. Generally, ß-HBA levels tended to be higher towards the end of exercise and immediately after work ended. This agrees with the conclusion that plasma concentrations of non esterified fatty acids (NEFA) and ß-hydroxy butyrate have been found to increase in exercised cows (Table 9) (Matthewman 1990).

Table 8. *Effects of work on physiological responses of oxen.*

Significant contrasts	
Plasma glucose	
WS vs. WNS	Pre-work and at 3 hr into work—higher in WS than WNS
INS vs. WNS	Only at 1 hr into recovery
Serum NEFA	
INS vs. WS	Only at 1 hr into work
INS vs. WNS	Only at 1 hr and 5 hr into work and 1 hr into recovery
WS vs. WNS	Only at 1 hr into recovery increased by 76.5% (WS) and 103.6% (WNS)
Plasma ß-hydroxy butyrate	
INS vs. WS	Only at 1 hr into recovery—higher for WNS than INS
INS vs. WNS	Only at 3 hr into work
Plasma lactate	
INS vs. WNS	Only at 1 hr into work

INS = Idle/non-supplemented
WNS = Work/non-supplemented
WS = Work/supplemented

Table 9. *Effect of work and feeding levels on dry matter intake (DMI, kg/d), average daily gain (ADG, g/d) and dry matter digestibility (DMD, g/kg) during the recovery period.*

	Treatments							Contrasts	
	1	2	3	4	5	6	SED	T1 vs. T2	T2 vs. T6
DMI	7.1	6.2	4.9	5.9	6.7	7.4	0.37	NS	**
ADG	280	566	275	443	529	558	68.5	***	NS
DMD	640	680	650	650	650	670	20.0	*	NS

On the other hand, plasma lactate concentration was not affected by work as lactate concentration did not differ among treatments. These results emphasise the important role played by both NEFA and glucose together, in maintaining energy homeostasis in oxen during exercise. Glucose and free fatty acids are important as energy substrates during work. This is especially essential for unsupplemented (thin) animals, which used less NEFA during work. The apparently greater use of NEFA by fat animals would suggest that in a short working season, fat animals could work using their fat reserves with minimum additional energy.

Effect of supplementation and work on thermoregulation

Rectal temperature increased by 4% (37.8 to 39.3°C) after 5 hrs of work for supplemented oxen and by 6.1% for unsupplemented oxen (Figure 5). Skin temperature rose by 3.3°C (from 33.7 to 37°C) after 5 hrs of walking and fell to 33.8°C, 4 hrs after exercise ended for the WS oxen and rose by 4.3°C for WNS group. In working and supplemented animals sweating rates rose from 78.9 g/m^2 per hour just before work started to 232.0 g/m^2 per hour during the 5 hrs work. Pulse rate (heart beat) was also affected by work. Working animals had higher heart beats ($p < 0.001$) than non-working animals. It also increased as work progressed increasing from 44.5 (SE 1.6) at 0 hr to 61.6 (SE 2.8) and 66.4 (SE 2.9) after 2.5 and 5 hrs of work, respectively.

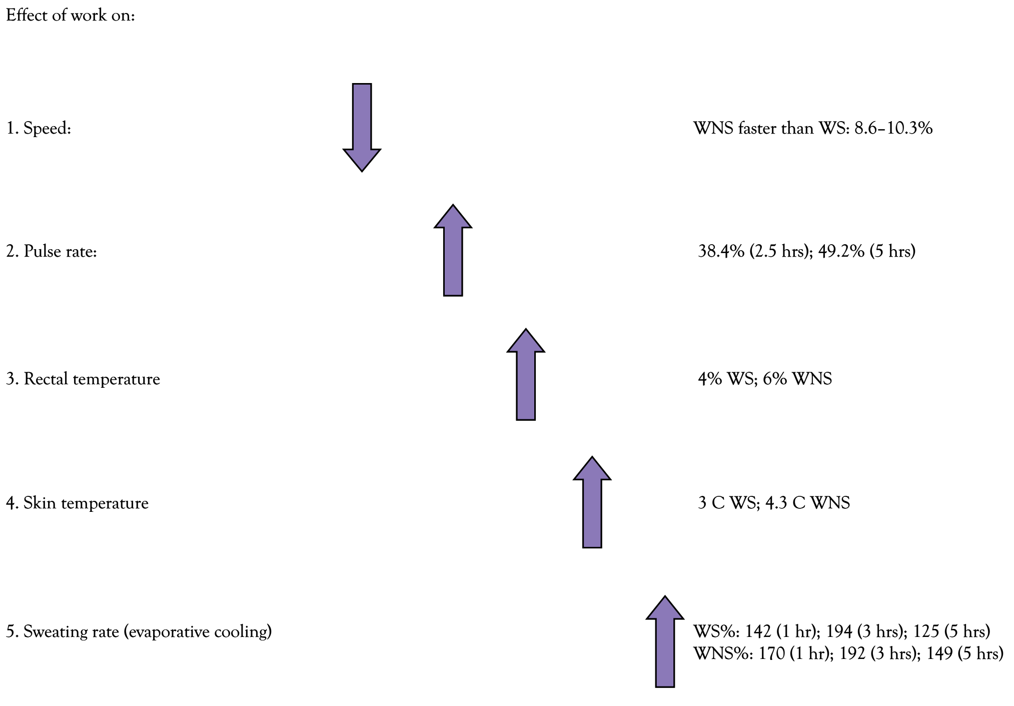


Figure 5. *Effect of work and supplementation on thermoregulation.*

Pulling distance, walking speed and energy expenditure

All animals within all work groups performed uniform work at uniform speed while they were fed at the same level ($p > 0.05$). The distance covered per day was the same for all animals within the different groups (17.2 ± 2.1 km/d). Higher speed was observed at the beginning of work (0.70 ± 0.02 m/s). This decreased to 0.64 ± 0.02 m/s after 2.5 hrs and was maintained at this speed up to 5 hrs. However, the WNS oxen walked faster than the WS oxen throughout the work hour. The walking speed decreased from 3.1 to 2.8 km/hr and from 3.2 to 2.8 km/hr for WS and WNS, respectively. Estimates of energy expenditure (Lawrence 1985) for walking were about the same for both WS and WNS oxen (2.63 vs. 2.5 J/m per kg). The WS oxen, however, expended more ($p < 0.001$) energy per day for walking than the WNS oxen (11.9 vs. 9.9 MJ/d, SE ± 0.157).

Effects of nutritional and work stress on feed intake and body weight change during the recovery period

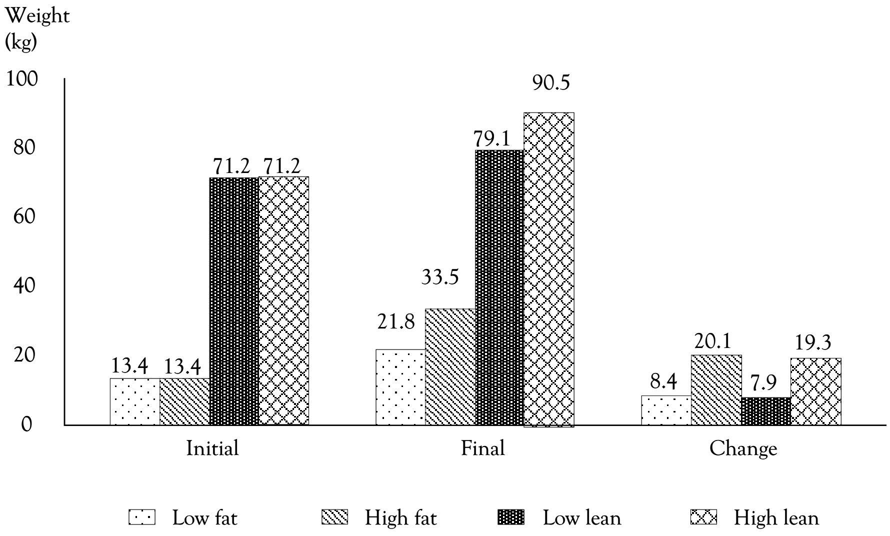
Feeding level and work had a significant ($p < 0.001$) effect on compensatory growth (Table 10). Energy restriction induced faster ($p < 0.001$) growth than in the control group (566.8 vs. 280.8 g/d). Both nutritionally and work stressed animals showed similar and higher body weight gain than the control during the recovery period. At the same levels of feed intake, continuous and restricted feeding caused two differing rates of live weight gain, during the re-alimentation period. Animals within the continuous feeding group showed similar weight gains to those groups assigned to work but receiving 0.7 times *ad libitum* during the recovery phase (280.8 vs. 275.7 g/d). However, the dry matter intake of continuously fed animals was higher ($p < 0.001$) than for treatment 3 (7.1 vs. 4.9 kg DM/d). This lower live weight gain by the control group is in agreement with ARC (1980), which showed a decreased efficiency of use of energy in ruminants when the level of feeding is increased for a prolonged period. Higher body weight gain by the restricted group during the compensatory period may be due to the fact that the restricted animals were invariably lighter and had a lower maintenance requirement during the period of re-alimentation. Thus, at similar intakes, more energy will be available for growth (Wright and Russel 1991). Cattle on restricted feeding had more efficient feed conversion than those on *ad libitum* feeding (Anderson 1975). There was no difference ($P > 0.05$) between nutritionally restricted groups and working groups in ADG and DMD at the recovery phase at the same level of feeding (Table 9). However, DMI and OMI were higher by 1.16 kg DM/d and 1.07 kg OM/d for the work groups respectively. Work had no ($p > 0.05$) effect on DM and OM digestibility. As expected, restricted feeding resulted in higher digestibility than did *ad libitum* feeding. At lower intakes better digestibility of feed is due to the longer feed retention in the rumen of restricted animals (Blaxter 1962).

Effect of level of feeding on carcass composition

The effect of nutrition on the carcass composition of Ethiopian Highland Zebu oxen are summarised in Figure 6. Beginning with similar initial lean and fat contents feeding level modified the carcass composition in terms of both the lean and fat composition.

Table 10. *Effect of three levels of feedings on intakes, digestibilities, rumen parameters and on live weight change in Highland Zebu steers.*

	Treatment				
	Low	Medium	High	Sem	Statistical significance of treatment
Intake g DM/d					
Hay	3.03	3.08	2.67	0.012	***
Supplement	–	0.32	1.58	0.004	***
Total	3.11	3.49	4.35	0.012	***
Intake g/kg LW^{75}	69.9	77.0	95.3	0.27	***
OM, g/d	2.82	3.17	3.99	0.011	***
NDF, g/d	2.31	2.5	2.78	0.009	***
ADOM, g/d	1.9	1.94	2.67	0.031	***
Digestibilities					
DMD, g/kg	636	587	652	5.2	***
OMD, g/kg	653	607	672	5.0	***
NDFD, g/kg	696	638	651	4.9	***
Rumen volume, kg	30.6	29.1	26.4	0.76	**
NDF Kinetics based on rumen evacuations					
K intake	0.041	0.044	0.055	0.0018	***
K passage	0.012	0.016	0.019	0.0006	***
K digestibility	0.028	0.028	0.036	0.0012	***
Micr. N supply, g/d	16.4	22	36.2	1.7	***
NEFA, meq/l	0.135	0.126	0.095		*
LWC, g/d	–101	109	425	14.7	***



Source: Osuji et al. (unpublished).

Figure 6. *Effect of different levels of supplementation on muscle fat and lean meat (kg) of Highland Zebu oxen fed teff straw basal diet.*

Effects of fluctuating feed supply

Ethiopian Highland Zebu steers, (24 animals, about 1.5 to 2 years old, live weight 130–160 kg (SD 13.7)) were used in the experiment. Twelve of the steers were rumen fistulated and six of these were also fistulated duodenally. Live weight (LW) of the animals was measured at the beginning of the experiment and once a week thereafter. Experimental treatments were: Low (L) Sululta hay fed at 80% of *ad libitum* (2% of LW) estimated to give 0.70 maintenance (Maint.); Medium (M) Sululta hay fed *ad libitum* + 0.2% LW of wheat bran (1.0 Maint.) and High (H) Sululta hay fed *ad libitum* + 1% LW of wheat bran (1.5 Maint.). Chemical composition (g/kg DM) of hay was OM = 925, NDF = 736, N = 8.64, and of wheat bran was OM = 956, NDF = 436 and N = 28.5. Experimental design consisted of two pairs of balanced 3 × 3 Latin squares with an extra period (the last treatment was repeated), so that all six combinations were covered (LMHH, LHMM, MLHH, MHLL, HLMM, HMLL). Each period lasted eight weeks and data were collected during the second, fifth and eighth weeks of each period.

Intakes were fixed based on live weights except for hay on M and H level (Table 10). Animals fed hay *ad libitum* did not eat as much as expected. However, quality of hay was better than expected when diets were selected. Based on its D-value (0.169*D–1.05; MAFF 1981), ME value was 9.9 MJ/kg DM with L and 9.3 MJ/kg DM with M. Wheat bran at H level decreased the intake of hay slightly (substitution rate 0.24). DM and OM digestibilities were highest with H due to the better digestibility of wheat bran rather than of hay. NDF digestibility was highest with L. This can be explained by slowest passage rate from the rumen while rate of digestion was the same for L and M but higher for H. Compared to small difference in intake between L and M, difference in live weight change was quite big. This can be expected to be a real difference in body weight since rumen volume was the same for L and M. Rumen volume was on average 4 kg less for H indicating that animals gained actually about 500 g/d. Blood NEFA concentration was highest with L, but the difference between H and M was small and not significant.

Conclusion

Undernutrition of tropical ruminants is a major area of study. Animals are undernourished because of fluctuating supply of nutrients, insufficient intake of available feeds or from inherent deficiencies in the available feeds. The challenge to nutritionists is to manage the undernutrition state in a way that best benefits the animals and by extension the smallholder ruminant producer.

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Coping with feed scarcity in Zimbabwe: Causes and consequences of undernutrition

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Summary

Causes and consequences of undernutrition among cattle in Zimbabwe are addressed in this paper, and how the smallholders have coped with feed scarcity over the years. The economic, climatic, land tenure and edaphic factors were highlighted as causes of undernutrition. Some strategies to address undernutrition in smallholder ruminant production systems in the region include feed budgeting, introducing and evaluating new forage crops and changes in land policies.

Introduction

This paper was written to acknowledge the causes and consequences of undernutrition among cattle in southern Africa. A detailed section is also included to elucidate how farmers have managed to cope with feed scarcity over the years with the help of researchers and other livestock practitioners.

Undernutrition implies energy deficit. The energy deficit may be due to sub-optimum intake of the feed or induced by limited intake as a result of low protein content or high fibre concentration in the diet (Lamond 1970). The economies of southern African countries are characterised by gross income and wealth inequalities between and within economic sectors and population groups (Graham 1987). Livestock production is not an exception to this rule. Large-scale commercial production and smallholder farming results in wide differences in productivity levels of livestock. Livestock in smallholder farming areas depend largely on communal grazing starting from early summer (November/December) until all crops have been harvested in May. Subsequently, cattle have access to patches of veld between cultivated land and to stubble grazing from harvested fields. Harvested crop residues become the main feed resource towards the end of the dry season (September and October). This is also the critical under-feeding period especially for draft cattle at the time of land preparation. In addition, it is also a critical period for pregnant and lactating cows and for young stock. If the onset of the rain is delayed, this results in reduced performance, conception and increased mortality. These limitations of cattle production in the smallholder sector are related to low quality and quantity of available forage. During the dry season, the crude protein content declines to 30–40 g/kg dry matter (Moyo 1996). The loss of quality is mainly due to lignification and translocating nutrients to fruit and root structures. Loss in quantity is mainly due to leaf shutter as the dry season progresses.

The situation in the large-scale commercial sector is different in that the cattle production system is capital intensive. The beef and the dairy production systems are well developed and compare well to farms in the developed countries (Mupunga and Dube 1992). Feeding in this sector is based on maize and its by-products for energy while soybean cake and cottonseed cake supply the protein. The sources of roughage are natural grass, standing hay or maize silage. Supplementing grazing cattle is carried out during periods of nutrient inadequacy, to maintain or reduce weight loss, and to produce and reproduce (Siebert and Hunter 1982). Three types of supplements that have been studied widely in Zimbabwe are vitamin A, phosphorus and protein-rich supplements. Supplementation mainly has an effect on improved fertility at the end of the dry season. For example, cottonseed cake at a rate of 800 g/day per animal, resulted in a fertility response that was 13% higher ($P < 0.05$) while 900 g/day per animal improved fecundity by about 23% (Siebert and Hunter 1982).

Although feed scarcity is a big challenge both in the smallholder and large-scale commercial sectors, opportunities exist for increasing forage production through the use of improved varieties, agronomic practices, chemical treatments and introducing browse in the form of multi-purpose trees. The other critical approach is to develop appropriate feed packages, which are based on local forages, browse, crop residues and processing by-products so as to improve efficiency of use (Mgheni et al. 1992).

Causes and consequences of undernutrition in cattle in southern Africa

Economic factors

The large-scale commercial cattle industry in Zimbabwe is largely dependent on feeds such as energy and protein concentrates, vitamins and mineral supplements, which are very expensive. This is more important during the dry season when natural grazing is poor. The purchase of these feeds, normally attract very high interest rates if borrowed money is used. If an ingredient has to be imported the weakening Zimbabwean dollar makes it even more difficult for farmers to stay in business.

Climatic factors

Cattle production in Zimbabwe (mainly in the smallholder sector) is to a great extent determined by the seasonal variations in the quantity and quality of the natural pasture (d'Hotman and Hatendi 1998). Zimbabwe's rainfall is uni-modal with a dry period of nearly 8 months, which causes serious challenges to the overall attainment of a marketable live weight of 450 kg. It is normal for cattle to lose weight and condition during the dry period, due to the unavoidable dry season undernutrition. The critical point is to prevent excessive weight loss because the cattle might fail to recover fully during the following rainy season. Periodic droughts aggravate the dry season undernutrition, and wide spread cattle deaths are a common feature.

The impact of drought in Zimbabwe on cattle mortality is shown in Table 1. Severe droughts were experienced during the 1983–84 and 1992–93 seasons. Nationally, close to a million heads of cattle were lost due to severe feed shortages in the 1992–93 drought. Mortalities during droughts are due to starvation and/or extreme water shortage. Some animals are slaughtered prior to death to salvage the meat. The low nutritional status is highly correlated (0.90) to disease susceptibility (Scoones et al. 1996).

Table 1. *Birth and deaths as a percentage of the total cattle population in the Mazviwa smallholder area.*

Years	1983–84	1984–85	1985–86	1990–91	1992–93	1994–95
Deaths	39.2	0.28	0.64	0.83	21.91	0.05
Births	0.97	18.11	22.87	12.74	1.5	12.8

Source: Scoones et al. (1996).

Land tenure and edaphic factors

An important aspect of cattle production in the Zimbabwean smallholder sector is the unresolved problems associated with land tenure and accountability. These continue to pose problems of overgrazing and also the unavailability of land to be used as collateral security for commercial borrowing (d'Hotman and Hatendi 1998). The continued deleterious effects of over-stocking and over-grazing in the smallholder sector are causing severe and potentially irreversible ecological degradation. This has been worsened further by the high human population growth rate of 3% per annum. The result has been intensive cultivation on lands better suited for cattle grazing. On average, about 40% of the smallholder sector is overpopulated, with a further 30% approaching a critical population density.

Poor soil quality and insufficient supply of underground water, also places severe limits on crop production, including those crops grown to provide forage for cattle (Topps and Oliver 1993).

Lack of appropriate technologies

Agricultural research in Zimbabwe up to independence in 1980 concentrated on large-scale commercial farm production. Technologies developed were merely assumed to be applicable to smallholder farmers as well. Failure of these technologies was blamed on poor or a lack of agricultural know-how of the smallholder farmers. However, it is now known that the technologies were not appropriate for smallholder, resource-poor farmers. Since data was obtained without involving the farmers, the research problems identified did not address the farmers' needs (Mpofu 1998). With the advent of farming systems research, smallholder farmers taken up a number of the technologies, e.g. stover treatment. However, there is still a lot of ground that needs to be covered if adopting technologies is to reach acceptable levels. Over the years, low adoption of technologies related to improved feed security of cattle has resulted in low productivity. Estimates consistently indicate that smallholder cattle production is very low, with an annual offtake of 1–3% only, compared to 18–20% in the large-scale commercial sector (van Hoffen 1993/94). Low offtake is a direct result of cattle production being characterised by poor calving percentages (45–50%), low live weight gains (30 kg/ha per year), long calving intervals (2–3 years) and delayed age at first calving (3–4 years) (Ministry of Lands, Agriculture and Rural Resettlement 1992). This low production is not peculiar to Zimbabwe alone, as similar poor production levels have been reported in neighbouring Botswana and Zambia (Perry et al. 1984).

In general, most livestock feeding projects in Zimbabwe (especially in the smallholder dairy sector) have registered a technology adoption rate of 10%, while a few technologies range from 50 to 75% (Mupunga and Dube 1992). These adoption rates were measured in terms of active or producing members out of total membership in the ten smallholder dairy schemes in existence at the moment.

Coping with feed scarcity

The cattle industry in Zimbabwe has made considerable progress in recovering from a series of periodic droughts since 1980. This was achieved mainly because farmers and the various other agricultural practitioners found it necessary to feed the cattle better and had to find some suitable form of grazing management. Although the total national herd shrunk as shown in Table 2, export of first grade beef, mainly from the large-scale producers to the European market has continued to increase.

Land policies

The Government of Zimbabwe has started a comprehensive national programme that focuses on overgrazing and overstocking. The programme that has already been implemented in many areas emphasises stock control, improved land management and encourages de-stocking. The on-going land redistribution to the indigenous people is a parallel effort, aimed at easing pressure on grazing so that undernutrition in cattle is minimised.

Table 2. *National cattle numbers (× 10^3) and exports (t).*

Year	Total head	Commercial	Communal	Exports (t)
1985	5172	1763	3409	–
1988	5822	1654	4168	–
1991	5985	1714	4271	4082
1992	5447	1642	3805	8969
1993	4877	1451	3424	10,001
1994	5301	1383	3918	14,604
1995	4711	1331	3380	12,790

Source: CSO (1996).

Feed budgeting

Farmers are coping with the economic difficulties through judicious feed budgeting. The feed budgeting programmes try to match the feed requirements of the stock held, with the quantity and quality of feed resources available at different times of the year (Clatworthy 1998). This exercise requires training especially to determine the grazing days.

The main advantage of feed budgeting as seen on the ground is that one can estimate when feed shortages will occur, as well as the possible duration of the shortage, and hence pre-plan on the appropriate method of overcoming the feed shortage.

About 20% of smallholder farmers in Zimbabwe now feed concentrates to their cattle to fatten them prior to marketing.

Table 3 gives summary data on the different feeding practices applied in two smallholder dairy centres—Nharira and Chikwaka.

Table 3. *Feeding practices as a % of all households.*

	Nharira	Chikwaka
Cattle owners	75	61
Feeding crop residues	82	53
Feeding crop (maize)	36	29
Concentrates	27	14

Source: Maphosa (1997).

Table 3 shows that a sizable proportion of smallholder farmers are feeding concentrates to increase their milk yields. However, feed budgeting has proved to be a critical management tool for viability reasons.

Changes to practices

About two-thirds of smallholders are convinced that milk yield can be increased from the current average yield of 3–4 kg to 9–12 kg of milk per day. As such new practices are being followed. These include improved veld management, feeding of home grown products, early weaning of calves and crossbreeding.

Awareness of the technical possibilities now exists, but what is often lacking is the know-how or inputs. Where constraints are minimal, strategic feeding is practised, for example cows are supplemented year-round to maximise milk yield and reproduction.

Irrigation has the potential of improving feed resources for cattle in Zimbabwe, especially during the dry season. There are 305 irrigation schemes in Zimbabwe, which are not being used efficiently to grow fodder crops. The potential of irrigation to provide water for legume plants like *Leucaena leucocephala* is being pursued rigorously, to boost protein supply to smallholder cattle. High yielding fodder such as Napier grass is also grown.

Feeding systems

Feeding systems used in the cattle industry in Zimbabwe are either intensive or extensive. The former makes use of bought concentrates and micronutrient supplements, with a small amount of grown forage. The latter is a grazing system for cattle, with limited or no supplementation. Commercial dairy cattle are fed intensively on diets that are high in concentrate and low in roughage. It is possible to produce a concentrate mixture from bought ingredients which has a crude protein content of 20% and a metabolisable energy value of 11.0 MJ per kg at a low cost (Topps and Oliver 1993). This is being achieved by using farm-grown materials, especially maize meal and irrigated star or rye grass with digestibility of over 70%. Farmers control the quality of the diet containing farm grown ingredients through the routine analysis of the individual ingredients. This enables them to formulate the diets more accurately. Analytical tests are also made to check for anti-nutritional factors such as aflatoxin in groundnut meals or tannins in multi-purpose trees. Commercial farmers are now accustomed to use milk replacer for calf rearing.

In the extensive system, the feeding systems used, normally do not match the requirements for energy and nitrogen substrates in the rumen to allow maximum synthesis of microbial matter. Improving the nutritional value of poor quality roughages has already gained momentum in the smallholder dairy sector. Urea treatment is used to treat roughage to improve their nutritional value and to make a substantial contribution to the nutrient intake. Simple chemical treatment packages have been devised where a tone of straw is treated with one bag (50 kg) of urea fertiliser dissolved in one drum (200 litres) of water. The straw is ensiled in pits or in small quantities in plastic bags for at least 4 to 7 weeks. The high ambient temperatures in Zimbabwe ensure rapid conversion of urea to ammonia. The result of the treatment is a softer (more digestible) roughage that is high in nitrogen content. Some smallholder dairy farmers have managed to increase their milk production from 3 kg to 10–12 kg/cow per day as a result of urea treatment. The main advantage of this technology is that urea is readily available in Zimbabwe and both small and large packages are obtainable in a manner that fit farmers' requirements.

Introducing and evaluating new forage crops

Planting of browse trees and shrubs as contour hedges is providing additional fodder to smallholder cattle. Experience has shown that smallholder farmers are very interested in planting trees and shrubs for feeding purposes, if adequate advice and the necessary inputs are made available.

Smallholder farmers selected several browse species and fodder cultivars for establishment. The criteria that have been used include:

1. The capacity to grow and produce large quantities of leafy forage in a hot and dry climate
2. High annual yields of crude protein (with a rumen degradability of 0.7 or greater) and of digestible energy and
3. Low content of anti-nutritional factors.

Many shrub legumes are now being grown and evaluated in a larger number of sites mainly with the help of the International Centre for Research on Agro-forestry (ICRAF). Some of the more popular shrub species are *Acacia bioliviana, A. seyal, A. nilotica, Calliandra callothyrus, Leucaena diversifolia, L. leucocephala and L. pallida* (Manyawu 1996).

The well-known *Pennisetum cultivar* named *Bana* has been established widely in the smallholder sector (Topps and Oliver 1993).

Some attempts have been made with cultivars of cassava, to improve yield of tubers and resistance to disease. This has been accompanied by the wilting of cassava foliage to reduce the content of tannins and cyanogenic glycosides (Topps and Oliver 1993).

For all these forages, harvesting procedures have been devised, and these are clearly explained to new farmers to maximise the yield of leafy material and yet sustain the viability of the plant. During research, each batch harvested is evaluated using the following determinants; dry matter, crude protein content, organic matter digestibility, rumen degradability of protein, acid detergent insoluble nitrogen and tannin levels.

Other measures to improve the feeding of cattle in Zimbabwe

Mobile milling and mixing facilities have been introduced to serve the needs of smallholder dairy farmers. This has largely been possible through donor funded projects. Some enterprising farmers have co-operated and purchased units that they are using in rotation among themselves.

Smallholder producers keep a relatively small number of cows (3–9) and depending on large-scale enterprises for the milling and mixing of diets is not economic. The idea of a communally owned chopping unit, used in rotation by different households, has been an attractive option. Specific attention has been given to equipment that rolls or crushes cereal grains and to the coarse milling of roughage so that complete ruminant livestock diets can be prepared.

Reducing the feed costs of livestock systems

Three main areas have been looked into in an attempt to reduce feed costs and to lower the chances of undernutrition.

Feed storage on most farms used to be organised badly, prior to the inception of the economic reform programme in 1990. This led to huge feed losses. Milling and mixing on most farms was also an untidy operation and led to excessive wastage. Providing ground concentrates to cattle on an *ad libitum* basis meant that feed was eaten by birds and rodents. The devaluated local currency and the high cost of inputs associated with the economic reform programme made it imperative for farmers to save money. Corrective measures to lower wastage to a minimum have led to a more efficient use of feed resources. Troughs used in concentrate feeding are now cleaned regularly to prevent the feed from becoming stale and the occurrence of oxidative rancidity. Concentrates are now fed at fixed times only, hence reducing wastage and spills.

Cattle are currently fed according to their requirements as has been mentioned above. This is a departure from the commonly held notion that excess feed will induce higher levels of production. These generous planes of nutrition have now been found to have little or no response in performance.

Changes in the dietary components have proved to make a small but significant saving in feed costs. This has been achieved mainly by changing the proportions of certain ingredients. For example, chemically treated straw is used partially or completely, to replace alfalfa hay in some diets (Topps and Oliver 1993).

Smallholder production of soybeans is increasing rapidly in Zimbabwe. Production increased approximately ten-fold from the 1996/97 to the 1997/98 seasons and is set to increase further in the coming seasons. As a result of this rapid expansion of soybean production, farmers now demand information on the feeding value of soybean stover, which is richer in nitrogen than maize stover, though more fibrous. Efforts are being made to come up with a package for these farmers so that they can use the soybean hay effectively.

Conclusion

With the continued participation of the concerned farmers, it is hoped sustainable strategies to manipulate crop residues will be designed to boost the smallholder livestock farmers' feed resources, both qualitatively and quantitatively.

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Undernutrition in dairy ruminants and intervention options for coping with feed scarcity in smallholder production systems in Uganda

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Summary

In Uganda, severe feed shortages are common during the dry seasons both in the pastoral and intensive ruminant feeding systems. Traditionally, farmers within the pastoral systems had adopted ways of coping with feed and water scarcity by migrating with their animals in search of pastures and water. However, this practice is becoming increasingly rare due to population pressures and the resulting land shortages. In the intensive dairy systems, farmers cope with feed scarcity by using non-conventional feedstuffs, which are not yet popular among smallholders. In this study, two parameters—total digestible nutrient (TDN) and digestible crude protein (DCP)—were used to estimate the pasture quality and nutritive value, and the nutritional quality of pastures in different agro-ecological zones of Uganda.

Introduction

In Uganda, efforts initiated nearly a decade ago to rehabilitate the dairy sector have succeeded in making the country self-reliant in milk production to meet urban market demands. Much of this success was attributed to the intensive dairy management in urban and peri-urban systems based on zero-grazing. However, new developments in milk processing and infrastructure improvement is tapping milk from the traditional pastoral systems. For example, recent statistics indicated that about 85% of the total marketed milk and beef in Uganda are produced from indigenous cattle, which thrive on natural pastures. The statistics also revealed that increased milk supply is likely to reduce prices and make peri-urban dairy economically unstable.

The use of the rangeland resources by wild and domestic animals has come under increasing pressure from increasing human habitation, cultivation, increasing grazing pressure and/or conflicting social interests. Therefore, improving rangeland management is necessary for improved livestock and game production in the country. The cheapest source of feeds, in Uganda, for livestock is natural pastures. However, they are of low quality, like most tropical pastures, because of the fast growth rate that occurs during the wet season. The quality decreases very fast with maturity and cannot therefore meet the nutritional requirements of the livestock. The nutritional problem of livestock on rangelands is exacerbated by environmental hazards such as drought/water shortage and overgrazing due to large numbers of livestock populations, which has led to range condition deterioration. The major indicators of rangeland degradation are shrub/bush encroachment, gullies as a result of water erosion and bare ground along cattle paths and resting grounds. All these indicators especially shrubs/bushes imply reduction in grazing land and suppression of palatable grasses like *Brachiaria* spp., *Setaria* spp., *Themeda triandra* and *Hyparrhenia rufa* and legumes like *Glycine* spp., *Desmodium* spp., *Siratro* and *Centrosema.*

To overcome the dry season severe feed shortages faced in the country by both the pastoral and intensive ruminant production systems, there is need to develop appropriate technologies for sustainable rangeland use for improved ruminant feeding, especially among dairy herds in Uganda. There is also the need to use other feed resources within the country.

Nutrient availability

Natural pasture constitutes the main feed resource in the rangelands and its yield and composition is affected by the stocking rate, which is determined by the carrying capacity of the rangeland. And the carrying capacity is significantly influenced by soil fertility, rainfall pattern, and the composition, quality and quantity of vegetation. In this study, two parameters—total digestible nutrient (TDN) and digestible crude protein (DCP)—were used to estimate the pasture quality and nutritive value, and the nutritional quality of pastures in different agro-ecological zones of Uganda (Table 1).

The estimated pasture production and carrying capacity of the agro-ecological zones in Uganda is also presented in Table 1, while the estimated consumable TDN and DCP by agro-ecological zones are presented in Table 2.

TDN availability and distribution

From the calculations of available TDN by district, there is a wide variation in the existing TDN supply, which is a function of the current level of stocking rate (the calculations were based on what is consumable).

Based on the above criteria, the districts most deficient in TDN presently are Kotido, Mbarara, Ntungamo and Tororo. These districts currently have livestock that greatly exceed the sustainable carrying capacity as indicated in Table 3. This implies that it will be necessary to control the number of stock in these districts and improve the herbage production.

Table 1. *Nutritive value, estimated average productivity and carrying capacity by agro-ecological zones in Uganda.*

Yield component	Banana–coffee	Banana –cotton	West Nile	Northern	Teso	Montane	Pastoral		
							Mb-arara	Bug-anda	Kara-moja
Total digestible nutrients (%)	51	54	53	54	54	52	51	51	51
Crude protein (%)	2.7	2.7	2.6	2.5	1.9	7.6	2.8	2.7	2.8
Available grazing land (km^2)	27,995	18,289	10,439	26,947	7930	16,365	4398	4553	25,566
Dry matter (t/ha)	5.3	4.25	4.68	4.5	4.25	4.5	3.9	3.9	1.68
Potential DM (× 10^6 t)	14.8	7.8	4.6	12.1	3.4	7.4	1.7	1.8	4.3
Potential TDN (× 10^6 t)	6.2	4.2	2.6	6.5	1.8	3.6	0.9	4.0	2.2
Carrying capacity (TLU/ha)	2.91	2.47	2.67	2.62	2.47	2.52	2.14	2.14	0.92

Notes: 1. Stocking capacity is based on a TDN requirement of 0.93 t per TLU per annum.
2. Figures in parentheses indicate stock above potential.
Source: GoU (1998).

Table 2. *Estimated consumable TDN (× 10^6 t) and consumable DCP (× 10^3 t) by agro-ecological zones in Uganda (based on dry season estimates).*

Yield component	Banana–coffee	Banana–cotton	West Nile	Northern	Teso	Montane	Pastoral		
							Mbarara	Buganda	Karamoja
Consumable TDN	2.071	1.4	0.863	2.183	0.607	1.204	0.992	0.302	0.73
Consumable required TDN	1.599	1.028	0.505	0.277	0.093	2.03	0.601	0.297	0.778
TDN balance	0.473	0.371	0.358	1.906	0.514	–0.827	–0.309	0.005	–0.008
Consumable DCP	109.7	70.0	42.3	101.1	21.4	172.1	15.4	16.0	40.1
Consumable required DCP	172.2	110.7	54.4	29.8	10.0	218.7	64.7	31.9	83.8
DCP balance	–62.5	–40.8	–12.1	71.3	11.4	–46.6	–9.3	–16	–43.7

Source: GoU (1998).

The districts of Moroto, Mbale, Pallisa, Kamuli, Iganga, Jinja, Western Masaka, Bushenyi, Rukungiri, Bundibugyo and Kabale also experience a deficit in TDN but of lower magnitude. Other parts of the country still have an untapped feed resources arising partly from the fact that some districts especially in the East (Soroti and Kumi) and North (Gulu, Kitgum, Lira and Apac) are de-stocked giving them the highest exploitable TDN (Figure 1).

Figure 1. *Areas with grass TDN surplus (deficit).*

DCP availability and distribution

Digestible crude protein presents a bigger constraint to livestock production than TDN from the estimates by district. Acute DCP shortage is observed during the dry season in the districts of Kotido, Moroto, Tororo, Iganga, Kamuli, Nebbi Mbarara, Ntungamo and Rukungiri. This may be attributed to high number of stocks and predominance of grass species that are in crude protein (Table 4). A DCP shortage of lower magnitude is experienced in Kabale, Bushenyi, Rakai, Masaka, Mubende, Mpigi, Mokono, Jinja, Luwero, Apac, Arua, Pallisa and Mbale districts. The rest of the country is not badly affected presently but caution must be taken when restocking since this will change the present situation.

Table 3. *Estimated and carrying capacity (× 10^3 TLU) by agro-ecological zones in Uganda (based on pasture productivity).*

Carrying capacity	Banana –coffee	Banana –cotton	West Nile	Northern	Teso	Montane	Pastoral		
							Mbarara	Buganda	Karamoja
Animal population (1995 census)	1338.1	949.2	466.5	255.4	85.3	1874.2	555.6	273.7	718
Potential population	1432.5	1292.1	796.7	2036.4	560.0	1111.0	269.2	402.5	674
Stock balance	574.4	342.9	330.2	1781.0	474.7	–763.3	–285.3	128.9	–44

Notes: 1. Consumable TDN and DCP is assumed to be one-third of potential yield, the rest being lost or unused for feeding. 2. Nutrient requirement is based on 0.93 t of TDN/TLU per annum and 50 g of DCP/day per 20 kg live weight. The nutrient balance is based on the 1998 livestock population estimates. Negative figures indicate deficit.

Source: GoU (1998).

Table 4. *Natural grass species predominant in Uganda with their nutritive value.*

Species	TDN (%)	CP (%)
Hyparrhenia filipendura	54	1.8
Panicum maximum	50	3.0
Brachiaria brizantha	50	3.4
Andropogon gayanus	55	3.4
Themeda triandra	54	2.5
Setaria sphacelata	52	2.7
Chrysopogon aucheri	48	3.5
Sporobolus marginatus	50	2.5
Cynadon dactylon	47	4.0
Pennisetum clandestinum	60	16.0

Source: GoU (1998).

Causes of undernutrition in ruminant livestock herds

From literature review, field observations and questionnaires conducted by GoU (1998) and MAAIF (1993) in Uganda, the following factors were identified as the major causes of undernutrition among the dairy and beef herds:

Rangeland degradation

The Meat Production Master Plan study conducted by GoU (1998) indicated that there was no extensive rangeland degradation in Uganda but localised, depending on the existence of pre-disposing factors. In the pastoral zone of south-western Uganda (the largest dairy products producing zone), rangeland degradation is demonstrated through changes in the botanical composition of the range leading to a serious weed problem. Foci of rangeland degradation are localised to livestock routes and around water sources such as Lake Kachera and Lake Mburo, along River Rwizi and Katonga. In Mbarara District, rangeland degradation is common on hill tops on communal grazing land in Isingiro, Rwampara and Nyabushozi counties.

Settlement and cultivating grazing areas

In some areas, especially in Ntungamo District, the problem of rangeland degradation is chiefly associated with the shrinkage of the grazing area due to human settlement and crop cultivation in areas that were traditionally used for grazing. As a result, the remaining grazing area has been overgrazed.

Overstocking

In Karamoja, it was observed that under the present methods of pasture and livestock management, many of the grazing areas are overstocked and accelerated erosion is a big menace. This is further exacerbated by low and unreliable rainfall (average less than 600 mm annually) and is concentrated in one season. Soil erosion has also destroyed water dams through silting.

Bush encroachment

The quantity of the pasture in most of the cattle corridor has diminished due to bush encroachment in areas that were previously open grassland. From the field observations, the problem of bush encroachment was very severe in the grazing areas of the south and south-western Uganda, where thorny acacias dominated.

The prevalence of unpalatable species in the herb layer has also greatly reduced the available consumable herbage. *Cymbopogan afronardus*, an aromatic weed has colonised a large section of grazing areas. Previous studies have shown that in some parts of the range, this weed accounts for up to 70% of the DM production in the herb layer. The causes of this change in botanical composition have not been established but changes in livestock population, indiscriminate use of fire, and heavy grazing pressure have been cited as the contributing factors. Control of this weed can substantially increase livestock production.

Interventions to increase productivity

Weed control/management

Weed poses a problem by hindering the development of the herbaceous cover and blocking the movement of livestock. The invasion by weed has reduced the available grazing land considerably in the ranching areas of the south and south-western Uganda where thorny bushes dominated by Acacias hockii have formed thickets. The problem is even more serious with poisonous weeds such as Lantana camara, Phytollaca and various species of the family Solanaceae. Nearly all the grazable areas have been encroached upon by trees, shrubs and thickets that comprise about 70% cover, thus reducing productivity of the rangelands. Herbage dry matter production in the undergrowth is considerably low (200 to 800 kg/ha). It is estimated that with weed control alone as an intervention, production will more than double (Table 5). Various methods have been tried for bush control including:

- use of well-timed fire which is believed to reduce woody species in favour of herbaceous species
- mechanical control which involves operations like hand hoeing, use of bulldozer, discing, chain rolling cutters etc.
- use of herbicides (this intervention did not have any lasting impact in Uganda) and
- biological control (this has not been tried in pasture improvement in Uganda and so more research needs to be done).

Table 5. *Mean herbage dry matter (DM) yield and chemical composition of pasture on two types of range management in Kazo, Uganda*

Parameter	Cleared farms	Bushy farms
DM (%)	27.5	30.1
CP (%)	9.2	8.9
NDF (%)	62.5	63.0
Dry matter yield (kg/ha)	2040	906
Crude protein yield (kg/ha)	182	86.0
Legume proportion (%)	7.4	2.3

Source: Mugasi (1999).

Introducing forage

Grasses and legumes of high nutritional value can be introduced in area, where they are known to be adaptable. This is possible in farms where the herds can be managed so as not to damage the introduced species before establishment.

Water management

Well-distributed water sources will improve the pastures by ensuring even use of the range by livestock. This will reduce the existing pressure on the watering points that are the foci of rangeland degradation.

Fertiliser application

Tropical soils are deficient in soil nutrients and therefore fertiliser use is one option of increasing forage production. This is only feasible under intensive production in the milk shade areas.

Irrigation

Areas with potential for irrigation should be exploited for forage production like the case of Mubuku irrigation scheme in Kasese District, which used to produce lucerne hay in the 1960s and early 1970s.

Potential feed resources and their management for improved ruminant nutrition

Undernutrition in Uganda occurs in the midst of vast feed resources that are untapped, which could make a major impact on livestock production. For instance, crop residues from crop production, and agricultural wastes and by-products from agricultural industries can be converted into meat and milk. A number of reasons such as human population pressure, scarcity and high cost of concentrate feeds, the long dry season in some parts of the country and the economic need to match livestock production systems with available resources justify increased use of these non-conventional feed resources for animal feeding. Moreover, their use not only improves animal production in terms of increased milk and meat production but they also play an important role in ameliorating the environment.

Crop residues

Uganda's climate is characterised by wet and dry seasons. During the wet season, there are usually plenty of pasture and fodder from natural grassland (pastures), waterways and roadsides. In the dry season, however, green forage becomes scarce and ruminants depend almost entirely on scrub vegetation and to a lesser extent on crop residues for their nutrients. As such, shortage of feed in the dry season is a major constraint in dairy production systems. The constraint can be partially mitigated by feeding crop residues. From the MAAIF (1993) and GoU (1998) studies, it was noted that in all the agro-ecological regions of the country, crop residues are not widely used, and this needs to be popularised to cope with undernutrition, especially in dairy herds, during the dry seasons. Table 6 shows some of the productive parameters associated with these feed resources.

Table 6. *Some productive parameters of major crop residues in Uganda.*

Category	Crop	Residue available for feeding (t)	TDN available (t)	DCP available (t)
Plantain	Banana (peels)	2,012,805	1,207,683	161,025
Cereals	Maize (stover and cobs)	920,755	374,412	8,231
	Millet (straw)	940,675	423,304	37,627
	Sorghum (stover)	223,992	107,198	2240
	Rice (straw)	12,763	4850	894
Legumes	Bean (haulm)	70,430	28,172	1759
	Cow pea (haulm)	6616	2646	166
	Field pea (haulm)	4784	2057	191
	Groundnut (haulm)	44,958	26,077	1799
	Pigeon pea (haulm)	25,101	10,040	1506
Tubers	Cassava (peels)	51,315	14,367	2872
	Sweet potato (vines)	181,090	126,763	25,172
	Irish potato (Peels)	9790	6854	548
Others	Simsim (straw)	35,437	15,592	1487
Total		4,505,074	2,350,244	245,517

Source: GoU (1998).

The estimated total supply of TDN from crop residues in Uganda is 2,350,244 t (Table 6). If a mature cow requires 1.3 t TDN per year, then it is possible that crop residues could supplement the nutritional needs of up to 2,169,456 TLU (Table 3), which is a very significant contribution. The usual practice in many areas is that, once the field is harvested, animals are allowed to move in to graze the residues. The major problem with this feeding system is that a lot of residues are destroyed by trampling during grazing resulting in considerable wastage of feed.

Based on the nutritive values of grassland, the contribution of crop residues to alleviate feed deficits from natural grazing (shown in Figure 1) are presented in Figures 2 and 3 for TDN and DCP, respectively. Figure 2 shows that, crop residues can meet fully the TDN deficits in most areas of Uganda with the exception of Kotido and Moroto in the north-east; Pallisa, Kamuli and Tororo in the east, and Mbarara and Rukungiri in the south-west. However, crop residues are unable to meet protein deficits in these districts plus Iganga, Mukono, Masaka, Mbarara and Ntungamo (Figure 3). This means that protein shortage is far more widespread in the country than TDN and any efforts to design interventions should pay particular attention to the supply of protein. Because of their relatively low nutritive value, crop residues need improvement to support higher production than maintenance, especially in dairy herds.

Figure 2. *Areas where crop residues cover the TDN grassland deficit.*

Improving the nutritional value of crop residues

Improved management and storage of crop residues

The feed value of crop residues could be greatly improved if they were cut soon after harvest and stored. Cutting and storing will minimise wastage from grazing and if done soon after harvest, will retain relatively good quality feed for livestock. Cereal residues would provide mainly energy (TDN) and if mixed with available forage legumes and haulms (which supply protein), the nutritive value of the crop residue would greatly be improved.

Figure 3. *Areas where crop residues cover the grassland DCP deficit.*

Integration with forage legumes

One way of achieving this would be through intercropping the forage legumes with the cereal food crops (Mpairwe 1998). The resulting crop residue could support a reasonable number of livestock in the smallholder systems especially during the dry season when feed supply from grazing is inadequate.

The most promising technology for Ugandan conditions is the maize–lablab intercrops for food and feed production in smallholder dairy production systems. Both plants can be intercropped on the same piece of land to reduce competition for land and labour in food and feed production. In an experiment to examine the effect of intercropping cereals with forage legumes, results of the data collected over a period of three years indicated that intercropping yielded 27% more fodder but slightly depressed grain yields (8%) compared with sole cereal cropping (Mpairwe 1998). Fodder DM yield of maize plus lablab (ML) intercrop, was 1.5 times higher (53.2% increase) than in sole maize while the nutritive value (crude protein, neutral detergent fibre (NDF) and dry matter degradability) of the fodder was greatly improved (Table 7). Crude protein content was 2.7 times (85.6 vs. 31.3 g/kg) in maize/lablab while the DM degradability (665 g/kg) of the intercropped forages (maize/lablab) was higher than that from sole cropped maize.

Table 7. *Effect of intercropping maize with lablab on grain, fodder dry matter (DM) yield and the nutritive value of the fodder.*

Parameter	Sole crop	Intercrop	Improvement (%)
Grain yield (kg/ha)	5773	4777	–17
Fodder DM (kg/ha)	9711	13957	44
Fodder CP (g/kg DM)	31.4	85.7	173
NDF (g/kg DM)	638	572	10
DMD (g/kg 48h)	590	669	13
CP yield (kg DM/ha)	305	1196	292

Source: Mpairwe (1998).

When maize/lablab feed alone was fed to crossbred cows over a lactation period of 140 days after calving (Table 10), it supported milk yield of 8.5 kg/cow per day, post-partum anoestrus interval (calving to 1st observed oestrus) ranged between 20–63 days (mean = 32) and a mean calving to conception interval of 95 days (Mpairwe 1998).

In another experiment conducted at Namulonge by NARO/NAARI (1996/97) to determine the effects of staggered planting on grain and herbage yields and quality of maize/lablab intercrops, results also showed that lablab planted concurrently with maize smothered the companion crop but improved the nutritive value of the fodder. Lablab was planted at 0, 15, 30 and 45 days after planting maize crop. Dry matter yields and protein contents increased linearly with increasing days after planting until 45 days. Fibre contents declined with time of introduction of lablab. The results suggested that staggered planting of maize and lablab at interval of 45 days after maize was a feasible option of increasing feed production and quality without affecting grain yield in smallholder dairy systems.

Chemical/physical treatment of crop residues

Technologies for physical and chemical treatment of crop residues are currently available. Physical treatments may include chopping and ensiling while chemical treatment involves the use of chemicals such as ammonia and sodium hydroxide. Because of the cost and labour involved in treating crop residues by these methods, the smallholder farmer should reserve treated residues for the neediest animals such as pregnant cows, lactating cows, calves and fattening animals. However, experience from many countries has shown that technologies for treating crop residues are usually not easily adopted by smallholder farmers due to a number of constraints. These include environmental hazards and labour demand as well as the cost and availability of chemicals. These issues do prevail in the Ugandan context. It is therefore reasonable to assume that this intervention will have a relatively minimal impact for some years to come.

The major constraints with the intervention of using crop residues would be the labour demand for harvesting, storing and feeding as well as competition for alternative uses such as fuel and incorporating in the soil as organic matter. Despite these constraints, a moderate increase of 1% per annum in the amount of crop residues stored could be expected within the next 20 years (GoU 1998). At this rate, some 2.8 million tonnes of TDN would be available to supplement the diet of 2.1 million TLU by the year 2015 (GoU 1998).

Improving pasture and fodder

Since crop residues are unable to meet all the feed deficit from natural grazing in many districts of Uganda (Figures 2 and 3), improved pastures and fodder should be considered in an effort to increase ruminant productivity, bearing in mind the cost of their establishment as well as management in relation to the prevailing meat and milk prices. A number of technologies could be applied to improve the productivity and nutritive value of pasture and fodder.

Over-sowing pastures with forage legumes

A more realistic approach of improving pastures in Uganda would be to employ over-sowing techniques for natural pasture development. Past experience has shown that desired species could be successfully introduced into natural pastures with minimum operations such as hard grazing, burning and minimum tillage. Legumes could be planted in spots and/or strips dug in the existing pasture. Legumes species recommended for over-sowing in Uganda include *Cook stylo, Verano stylo, Seca stylo, Siratro, Desmodium, Glycine* and *Centrosema* spp.

Using multi-purpose trees (MPTs)

Multi-purpose trees are deep-rooted shrubs or trees that are often drought-tolerant and if leguminous, do provide forage of high nutritive value. Using MPTs is encouraged because they fit well into the smallholder crop–livestock production systems: they provide quality feed to livestock, they are environmentally friendly and they provide a variety of other uses such as soil fertility improvement, fuel wood and poles.

These shrubs can be fed to livestock in the green form throughout the year. They can also be fed as hay or as a meal during the dry season. Because of the widespread animal protein shortage in Uganda, MPTs can be used as an important protein supplement for various categories of livestock, particularly dairy cattle, lactating indigenous cattle, calves, fattening beef cattle, sheep and goats. There are several ways of introducing fodder shrubs in the farming systems:

- as shade trees and windbreaks around homesteads
- as live fences
- as reserves in small areas for firewood, timber and fencing materials
- where it is easy to exclude cattle from the cropping areas, one can also plant the MPTs on contour banks, borders and corners. The MPTs could then be used for soil fertility build up, erosion control and as additional cattle feed and
- most zero grazing farms in Uganda have access to elephant grass. Practically all of it is grown without a legume because of the difficulty of growing them together. The best strategy should be to grow a small area of MPTs as a fodder bank and during feeding, up to 20% of the shrub legume can be mixed with the chopped elephant grass.

From consultations in the districts, it was pointed out that, currently, there are several agro-forestry programmes, which are operational in the country such as that by the International Centre for Research on Agro-forestry (ICRAF), which encourages planting of MPTs. These programmes should be encouraged and facilitated.

Establishing fodder banks

To increase the protein bank in smallholder farming systems, small areas of cropland could be earmarked for establishing herbaceous legumes. Short duration legumes are preferred because they can easily be plowed up when the area is needed for crop production. Plowing will add nitrogen to the soil for the benefit of subsequent crops. This will reduce the need for the expensive and environmentally unfriendly inorganic fertilisers. The best strategy should be to grow a small area or block of a legume, which can be used to feed livestock during the dry season. The area selected for the fodder bank should be where the livestock movement can be controlled. A fallow or grazing land is preferable for establishing legumes. Livestock can get access to the fodder bank in various ways. They may graze the fodder for say two hours in a day and then go out to graze on natural pastures or alternatively, they can be fed on cut green fodder or hay.

Herbaceous legumes should be fed to high producing animals such as dairy cows, dairy steers for beef, fattening cattle, lactating indigenous cows, draft oxen, sheep and goats. About 14 forage legumes have recently been recommended for different farming systems in Uganda (Table 8). These legumes have high biomass yield (1500–6500 kg DM/ha), a reasonable level of persistence at several sites in Uganda and a high seed production potential.

Table 8. *A list of the adapted and productive herbaceous legumes for Uganda.*

Species	Mean crude protein (%)	*In vitro* dry matter digestibility (%)
Desmodium uncinatum (Silver leaf Desmodium)	17.35	–
D. discolor	20.85	–
D. intortum (Greenleaf Desmodium)	15.87	44.54
Cajanus cajan (Pigeon pea)	16.9	–
Stylosanthes guyanensis (Stylo)	14.25	43.28
S. scabra (Stylo)	–	–
S. viscosa (Stylo)	–	–
Macroptilium atropurpureum (Siratro)	18.4	44.77
Lablab purpureus (Lablab)	16.95	54.95
Neonotonia wightii (Glycine)	17.35	75.38
Desmanthus virgatus	12.8	–
Clitoria ternatea	18.45	–
Macrotyloma axillare	11.9	–
Macroptilium bracteatum	–	–

Source: Sabiiti et al. (1994).

Feeding management: Strategic supplementation with forage legumes and agro-industrial by-products

Supplementation with commercial concentrates, e.g. dairy meal is an option for meeting the nutrient requirements of ruminants consuming low quality and inadequate tropical grasses and crop residues. However, their high costs and unavailability to smallholder dairy productions is a major limiting factor for their use in Uganda. Forage legumes with or without agro-industrial by-products have been proven to improve ruminant nutrition in the tropics and could support high levels of dairy production.

The results from a study on the effect of lablab hay supplementation of crossbred cows fed maize–lablab (ML) stover diet on feed intake, apparent digestibility, milk yield and milk composition, and reproductive efficiency (Mpairwe 1998) indicated an improved rumen environment (pH >6.2; NH3 concentration >3.5 mmol/l and total VFAs production >100 mmol/l). This was reflected in the improved passage rates of particulate digesta and the rates of DM, OM, N and NDF degradation was greater than 3% per hour. With the basal forage (ML stover), the average milk yield was 8.5 kg/cow per day while supplementing lablab hay to cows increased milk yield and improved reproductive efficiency of crossbred cows over a lactation period of 140 days after calving (Table 10). From the study, it was recommended that for optimum milk production and reproductive efficiency, crossbred cows fed ML stover basal diet should be supplemented with 0.5% BW lablab hay. This optimum level of supplementation was associated with milk yield of 8.8 kg/cow per day, post-partum anoestrus interval of 36 days and a calving to conception interval of 72 days.

Supplementing with graded levels of wheat bran at the recommended level of lablab supplementation resulted in higher milk production and better reproductive performance of the crossbred cows (Table 10). Using wheat bran and lablab hay as supplements to cows fed ML stover increased milk yield by 27% and reduced post-partum anoestrus interval (calving to 1st observed oestrus) by 34% (54 vs. 36 days) with a calving to conception interval of 80 days. The response in milk yield was a linear ($p < 0.001$; R2 = 0.996) resulting in a mean increment of 1.09 kg milk per kg increase of wheat bran DM intake. From this experiment, it was recommended that cows fed ML stover basal forage should be supplemented with 2.5 kg DM/head per day of wheat bran in addition to 0.5% BW lablab hay for optimum milk yield and reproductive efficiency.

Forage legumes are high protein sources that could partially substitute the concentrates in the rations of dairy ruminants. The level of substitution differs among legumes. A study was undertaken at Namulonge (NARO/NAARI 1996/97) to determine the optimum levels of lablab hay and concentrate supplementation to lactating crossbred cows. Each cow was fed 3 kg lablab hay, *ad libitum* elephant grass (*Pennisetum purpureum*) and varying levels of dairy meal (0, 1.2 and 3 kg respectively) in a Latin square design. The results (Table 11) showed that roughage intake was depressed by 1.4% while total DMI increased by 12.7%. Milk yield increased with increasing levels of concentrate feeding. The results revealed that additional feeding levels of dairy meal above 2 kg did not cause significant increase in milk yield. It was therefore concluded that lactating cows producing less than 10 kg of milk required amount of dairy meal not exceeding 2 kg/day for optimal production.

In a NAARI (NARO/NAARI 1996/97) initiated farmer participatory evaluation involving the use of MPT calliandra, the farmers were advised to feed 2 kg of calliandra hay mixed with dairy meal. Results showed that milk yields increased by 1 litre when cows were fed mixtures of concentrates and calliandra. No significant response was observed when the browse was fed without concentrates.

From these examples, it is clearly shown that strategic supplementation with forage legumes with concentrates or agro-industrial by-products improves ruminant nutrition.

Integrating crop–livestock technologies for improving feed supply and quality

To overcome seasonal nutritional constraints, increasing feed production and quality is needed in all parts of Uganda.

Integrating grain and forage legumes and browse trees can serve an important role in sustaining the productivity of crops and livestock in many parts of Uganda. Where fallowing is practised, legume, which fixes atmospheric nitrogen, can be more effective than indigenous grasses in restoring soil fertility, thereby reducing fallow period. Forage legumes can improve animal's feed, suppress weed growth, accelerate nutrient cycling and improve soil moisture conservation. Wind breaks using leguminous browse can control soil erosion, enhance soil productivity and provide food, fodder and wood.

Research has shown that integrating forage legumes with cereal crops (e.g. through inter-cropping, under-sowing, rotation) can lead to sustainable increase in feed and soil productivity. However, forages are rarely grown, probably because they do not contribute directly to food security. Also, when forage legumes are inter-cropped with cereals, there may be initial trade-offs in grain and feed output. Forage legume–cereal inter-cropping often increases the quantity and feeding value of crop residues, but decreases the yield of the cereal crop. However, grain yields appear to improve if the cereal is rotated with short-term fallows of forage legumes. Grain legumes (cowpeas, pigeon peas, groundnuts etc.) are already an integral part of many mixed farming systems in Uganda. Their residues are valuable diet supplements for livestock.

Agro-industrial by-products

Crops that produce agro-industrial by-products are grown in various parts of Uganda. Since the area of production is not necessarily the site of processing, the use of agro-industrial by-products should be viewed from a national perspective rather than as products from specific regions. The major ones are maize bran, wheat bran, cottonseed cake, sunflower cake, soybean cake, sugarcane by-products, coffee husks and brewer's residue.

The supplies and nutritive values of these by-products are summarised in Table 9. The table shows that the major TDN supplies are maize bran, soybean cake, coffee husks, bagasse and molasses. Protein is found mainly in maize bran, cottonseed cake, sunflower cake and soybean cake. The other agro-industrial by-products are important in local areas.

Table 9. *The supplies and nutritive value of agricultural by-products in Uganda.*

Residue	TDN (t)	DCP (t)
Maize bran*	251,635	17,758
Rice bran	6121	929
Wheat bran	4774	924
Cottonseed cake	5525	2876
Sunflower cake	8734	3822
Soybean cake	31,610	15,389
Molasses	12,324	265
Sugarcane tops	7610	367
Bagasse	24,724	706
Coffee husks	26,570	213
Brewer's grain	966	206

* Maize bran was calculated using a bran:grain ratio of 0.35 and availability of 90%.
Source: GoU (1998).

Conserving fodder

Forage conservation allows for intensive livestock farming with a higher stocking rate than would otherwise be possible. Making good quality hay is not easy in many areas of Uganda partly because conditions are too humid during the wet season and pasture quality is too low in the dry season. However, haymaking should be possible in those regions with a longer dry season such as the north, north-eastern and south-western parts.

Table 10. *Mean daily intake, milk yield and reproductive performance of crossbred cows fed* ad libitum *maize–lablab (ML) stover basal diet supplemented with graded levels of lablab hay (% BW) or lablab hay + graded levels of wheat bran (kg DM) for 140 days post-partum.*

		Daily intake			Reproductive performance	
Treatment Basal diet		TDMI (g)	CPI (g)	Milk yield (kg/day)	Calving to oestrus (days)	Calving to conception (days)
Experiment 1 (supplement: lablab)						
Maize–lablab	0.0	10.1	978	8.37	60.2	95.2
	0.4	11.0	1170	9.54	58.8	75.5
	0.8	10.3	1193	7.94	43.2	89.2
	1.2	10.1	1297	7.42	43.0	93.2
Experiment 2 (supplement: wheat bran)						
ML + 0.5% lablab	0.0	8.8	860	8.27	53.0	76.8
	1.4	10.5	1064	9.85	45.2	83.0
	2.8	10.5	1166	10.97	43.3	75.2
	4.3	11.3	1312	11.72	41.5	95.0

Source: Mpairwe (1998).

Table 11. *Intake and milk yield components in crossbred cows fed elephant grass + lablab hay with varying levels of concentrate (dairy meal).*

	Concentrate levels (kg/cow per day)			
Parameters	0	1	2	3
Roughage intake (kg/day)	10.6	9.8	9.6	9.1
Concentrate intake (kg/day)	0.0	0.9	1.8	2.7
Total DM intake (kg/day)	10.6	10.7	11.4	11.8
ME intake (Mcal/day)	21.5	22.0	23.9	25.2
CP intake (g/day)	1163	1225	1371	1471
Milk yield (kg/day)	9.8	10.4	11.3	11.0
Butter fat (%)	3.9	3.8	3.9	3.8
FCM yield	9.5	10.0	10.9	11.1

Source: NARO/NAARI (1996/97).

Silage making is not weather dependent, hence it can be made any time of the year and anywhere in Uganda. However, silage making requires a lot of skill if quality is to be maintained. The silage can be made from green maize deliberately grown for the purpose. It can also be made from maize during periods of maize crop failure. Other materials that can be used for silage making include elephant grass and sugarcane tops. Ensiled poultry litter, including coffee husk-based poultry litter, should also be tried since their potential in feedlots has been demonstrated.

Zero grazing

Farming systems in Uganda are increasingly tending towards intensive and semi-intensive systems. Many farmers today, especially dairy farmers in and around urban areas and in parts of the country with land pressure problems like Mbale District, are raising high yielding dairy animals under zero grazing system.

Currently, a dairy herd is fed about 65 kg of elephant grass daily. The leaf is cut from the stem, chopped and then fed. The stem may be used to mulch coffee or banana plants. Sweet potato vines, banana peelings, banana stems and occasionally concentrates are also fed. The elephant grass is usually widely spaced and is cut when it is mature. The diet of the animal is consequently deficient in both digestible protein and energy.

The elephant grass/legume pasture could be cropped on a 3-year rotation basis (e.g. 3 years crop and 3 years pasture). The fertility build up in the pasture phase of the rotation would increase and sustain crop yields. Manure would be returned to the coffee or to the elephant grass. The fodder grass and forage legumes would be harvested on a 6–8 week cutting regime. Crop residues would be fed when available and banana peelings would be fed throughout the year. Leucaena would be used mainly when the quality of the other forages is low. Surplus leucaena could be used as a mulch. Good management and efficient feeding can significantly increase the quantity and quality of forage produced per unit area. Zero grazing therefore provides a good opportunity for integrating crops and livestock in the farming system.

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Influence of plane of nutrition on productivity of ruminants in the sub-humid zone of West Africa

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Summary

A brief review of the effects of plane of nutrition on growth and reproductive performance of cattle, sheep and goats in West Africa is presented with reference to energy, protein and mineral levels in the diet, and the interaction between plane of nutrition and disease risk. Current strategies for coping with the consequences of undernutrition are outlined and future research needs suggested.

Introduction

In most part of sub-Saharan Africa (SSA), natural pastures, crop residues and indigenous fodder trees are the main feed resources for ruminant livestock, with natural pastures and crop residues providing the bulk of most basal diets. Due to seasonal fluctuations in the availability and quality of these feed resources, intake of energy, protein and some essential minerals by most ruminants species fall below their maintenance requirements resulting in 'undernutrition' and low productivity in most production systems. This paper gives a brief review of the effects of plane of nutrition on growth and reproductive performance of cattle, sheep and goats in sub-humid zone of West Africa with special reference to energy, protein and mineral levels in the diet, and the interaction between plane of nutrition and disease risk. Strategies for coping with the consequences of undernutrition and future research needs are also presented.

Effect on productivity of protein level in the diet

Nitrogen (N) is the most limiting nutrient in ruminant diets in most parts of the tropics, especially during the dry season. Results of several studies in West Africa show that low levels of nitrogen in the diet of growing cattle could result in reduced growth rate, delayed age at puberty, delayed age at first calving and higher compensatory growth rate (Umoh

1980; Oyedipe et al. 1983; Little et al. 1990; Agyemang et al. 1997). Live weight gain of Bunaji heifers increased with increasing crude protein (CP) in the diet (Table 1). In pregnant and lactating cows, Agyemang et al. (1997) reported that high levels of N in the diet increased milk yield and offtake, calf growth and conception rate (Table 2), while low N levels in the diet were associated with higher dam weight loss, low calf birth weight, high calf mortality, prolonged parturition interval, and increased risk of abortions (Little et al. 1991).

Table 1. *Effect of levels of crude protein in sheep and cattle diets on daily weight gain.*

Species	Crude protein (g/kg)	Weight gain (kg/day)
Yankasa ewes[1]	84	0.13
	156	0.17
	191	0.21
Bunaji heifers[2]	83	0.12
	134	0.41
	192	0.58

Sources: 1. Adu and Lakpini (1980), 2. Oyedipe et al. (1983).

Table 2. *Effect of supplementation with groundnut cake during the dry season on milk offtake, calf growth rate and conception rate of lactating N'Dama cows.*

Groundnut cake (g/head per day)	Milk offtake (litre)	Calf growth (kg/day)	Conception rate (%)
0	56	0.12	36
425	75	0.15	64
850	110	0.19	64

Source: Agyemang et al. (1997).

Oyedipe et al. (1983, 1984) found that Bunaji heifers on low N diets had lower serum total protein and copper concentration than those on high N diets. Serum total protein was found to be a good predictor of growth rate for animals fed on the low CP diet, suggesting that serum total protein could be useful in monitoring growth performance of animals reared on poor pastures as in cattle under pastoral production systems.

As shown in Table 1, reduced growth rate attributed to low levels of dietary N has also been reported in sheep (Adu and Lakpini 1980; Lakpini et al. 1982; Kwatu et al. 1983). Sheep on low N diets have also been shown to exhibit a higher degree of compensatory growth than those on high N diets (Otchere et al. 1977; Lakpini et al. 1982). Baring other adverse effects, this observation would seem to suggest that farmers who cannot afford protein supplement to their livestock during the dry season could take advantage of the higher compensatory growth rate of non-supplemented animals during the wet season. However, more research is needed on the effect of low plane of nutrition during the dry season on subsequent growth during the rainy season and its implications on smallholder livestock producers who depend largely on grazing to support animal production.

In pregnant goats, undernutrition could lead to abortion and neonatal death due to low birth weight (Osuagwuh and Akpokodje 1981, 1986). Low levels of concentrate in the diet during mid-pregnancy could lead to low birth weight, high mortality and slow neonatal growth rate (Table 3). As shown in Figure 1, use of *Stylosanthes guianensis* fodder bank as protein supplement to goats grazing natural pastures during the dry season could reduce the rate of weight loss (Ikwuegbu and Ofodile 1994).

Table 3. *Birth weight, neonatal survival and neonatal growth rate of West African Dwarf goats fed varying quantities of concentrates during pregnancy.*

	Concentrate ($g/kg\ BW^{0.75}$)	
Parameter	25	50
Mean birth weight (kg)	1.05	1.4
Neonatal survival (%)	57.0	100
Neonatal growth rate (kg/day)	0.55	0.78

Source: Osuagwuh (1992).

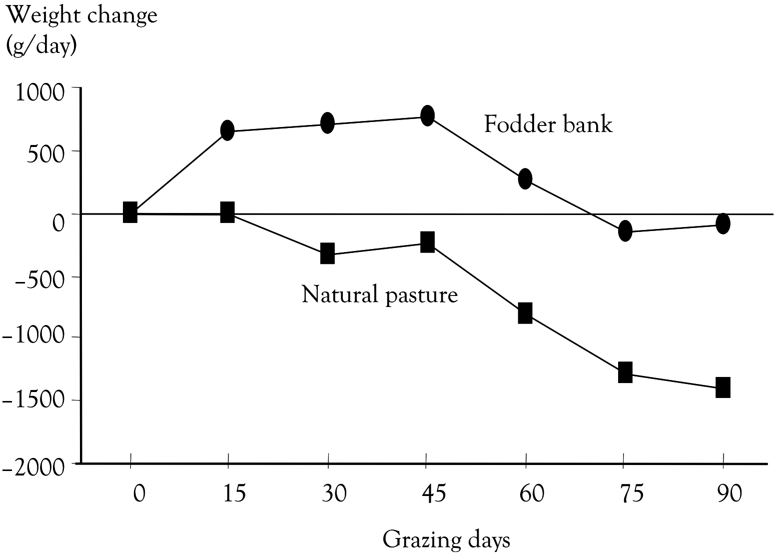
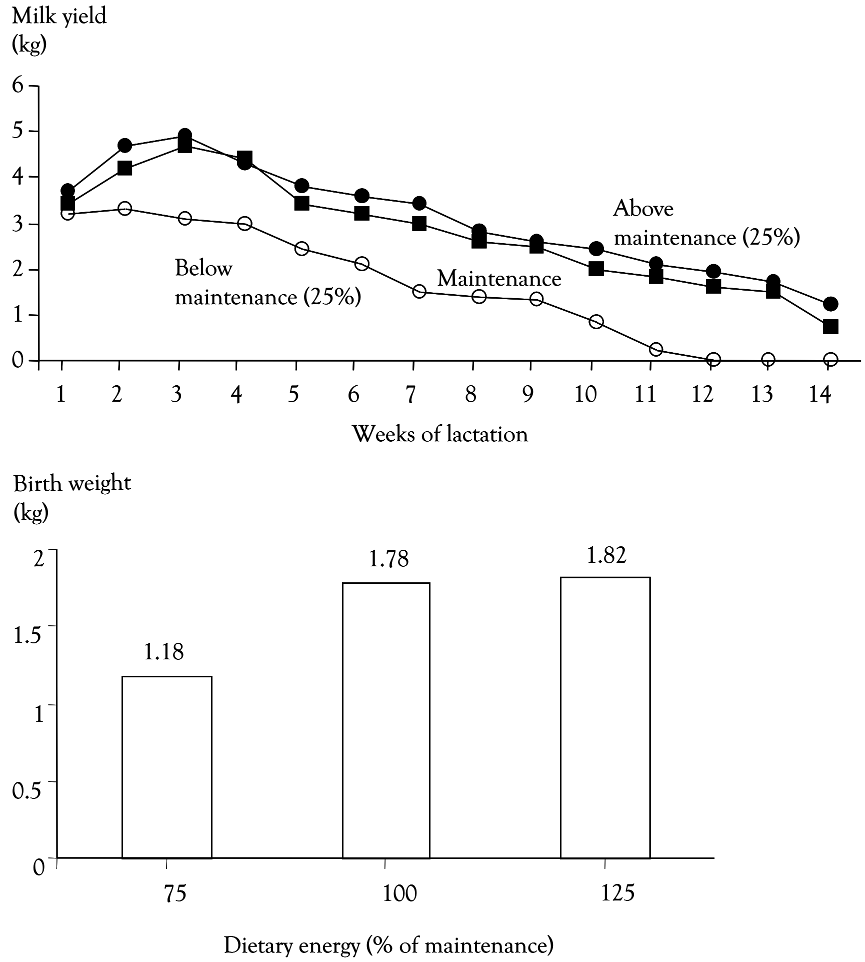


Figure 1. *Changes in live weight of West African Dwarf goats grazing natural pastures alone or natural pastures with access to a* Stylosanthes guianensis *fodder bank as protein supplement.*

Effect of low dietary energy on productivity

Diets deficient in energy retard growth and reduce reproductive performance in sheep (Kwatu et al. 1983) and cattle (Umoh 1980). In Yankasa rams, low energy diets reduced growth rate and body weight, and delayed age at puberty (Akpa et al. 1994). Energy levels below maintenance requirements in the diet of pregnant ewe increased maternal weight loss, and reduced low milk yield and lamb birth weight (Figure 2). Nianogo and Ilboudo (1994) observed similar results in Sahelian does.



Source: Adu et al. (1981).

Figure 2. *Effect of energy levels in the diet of pregnant West African Dwarf sheep on (a) milk yield and (b) lamb birth weight.*

Effect of low dietary mineral levels on productivity

Chemical analysis of available feed resources and soil from various parts of West Africa indicated that deficiency of essential minerals, particularly phosphorus (P) could limit productivity of cattle, sheep and goats in smallholder farming systems in the region. In cattle, P and calcium (Ca) deficiency could result in reduced growth rate, poor body condition, prolonged parturition interval, low birth weight, reduced milk yield and high calf mortality (Ikwegbu and Campbell 1992; Agyemang et al. 1997). In a 3-year study in central Nigeria involving 400 Bunaji cattle from 12 herds, Ikwegbu and Campbell (1992) reported that supplementing Bunaji cows under traditional management conditions with

P-rich mineral block improved calf birth weight, post-natal growth rate and survival rate. In the Gambia, Agyemang et al. (1997) found that growth rate of N'Dama calves suckling cows supplemented with salt at 50 g/head per day was relatively higher than those suckling cows that did not receive salt supplement.

Interaction of disease and nutritional status on productivity

Nutritional status of the host is an important factor affecting the susceptibility of trypanotolerant animals to infection with trypanosomosis. High plane of nutrition has been shown to reduce the severity of infection in N'Dama cattle under grazing (Agyemang et al. 1990; Little et al. 1990). These authors also reported that animals on a high plane of nutrition recovered more rapidly from anaemia while the packed cell volume (PCV) levels in animals on a lower plane of nutrition declined more rapidly. These results suggest that there is a critical level of nutrition, below which animals are no longer able to resist disease challenge. Live weight of infected pregnant ewes on a high plane of nutrition was higher than those on a low plane of nutrition (Table 4). Survival of lambs born to infected ewes on low plane of nutrition was lower than those born to ewes on a high plane of nutrition (Reynolds and Ekwuruke 1988; Akinbamijo et al. 1994 a, b).

Table 4. *Effect of plane of nutrition on weight change and survival rate of West African Dwarf sheep infected with* Tyrpanosoma vivax.

Physiological state	Plane of nutrition	Weight change (kg)	Survival (%)
Pregnant[1]	Medium	0.37	–
	High	0.33	–
Lactating[2]	Low	–	50
	High	–	100

Sources: 1. Akinbamijo et al. (1994), 2. Reynolds and Ekuruke (1988).

Current strategies for coping with undernutrition

Individual farmers and governments in the region have adopted several strategies to cope with undernutrition. Crop–livestock farmers have adopted cropping systems such as cereal–legume inter-cropping and planting of dual-purpose cereal (maize, sorghum, millet), grain legume (cowpea, groundnut) and root/tuber (cassava, sweet potato) to increase both the quantity and quality of dry season feed for their livestock. Others have adopted technologies that integrate forage legumes into cropping systems, e.g. fodder bank and intensive feed gardens, and alley farming. Farmers also process and store crop residues for dry season feeding, while peri-urban producers purchase supplements such as agro-industrial by-products for strategic supplementation.

Governments in some countries in the region have taken steps to cope with undernutrition in ruminants. For example in Nigeria, 'grazing reserves' have been established to encourage settlement of pastoralist as well as to reduce conflict between crop and livestock farmers. Governments in the region attempted to improve the quality of natural pastures through over-seeding, and to encourage adoption of improved feeding systems such as fodder banks, intensive feed gardens and strategic supplementation.

Conclusion

To cope with undernutrition and improve productivity of ruminants in West Africa, further research is needed on several aspects. Socio-economic studies are required on indigenous knowledge, gender issues and policies for efficient management of communal grazing lands. More information is needed on strategies for increasing feed supply such as identifying drought tolerant forages, conservation methods, feed budgeting and improved cropping systems to increase yield and quality of crop residues. Appropriate technologies are needed to exploit residual moisture in inland valleys to produce dry season feed. Further research is also needed to improve use of the available feed resources, especially crop residues. Research activities may include: developing methods for detecting undernutrition in the field, documenting the nutrient requirements of indigenous ruminant breeds, developing appropriate post-harvest and supplementation technologies. Limited evidence in the region showed differences in the efficiency of use of roughage diets among breeds (Ikhatua and Olubajo 1981), hence further research is needed to match breeds with the available feed resources. Finally, there is the need to investigate the environmental and socio-economic impact of undernutrition in the various ecological zones and farming systems.

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Nutritional constraints to grazing ruminants in the millet–cowpea–livestock farming system of the Sahel

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Summary

Growing pearl millet and cowpea in combination with raising ruminant livestock is widely practised in the Sahel. In this farming system, livestock feeding depends mostly on rangeland, fallows and cropland grazing. Nutritional constraints to grazing ruminants stem primarily from feed scarcity and seasonal fluctuations in feed supply associated with low rainfall and poor soil fertility. Low feed quality exacerbates the effects of feed scarcity and seasonality. Some herd management practices result in decreased grazing times and feed intake and (or) increased energy expenditure for walking. Land tenure and use rights, among other socio-economic factors, constrain the nutrition of livestock by limiting herd mobility and access to feed resources. Expansion of cropping areas onto rangeland may result in higher overall feed yields but limits feed availability and access to grazing lands during the rainy season. Nutrition of livestock can be improved with better herd and range management practices, increasing the quantity and quality of feed produced on range and cropland and by using feed supplements. These options need to be profitable and compatible with the resource endowment and production objectives to be adopted by farmers. Policies and institutional arrangements are also required to facilitate herd mobility and access to water and grazing land and to solve and prevent conflicts among users of these resources.

Introduction

Mixed crop–livestock farming and pastoralism are the predominant forms of agricultural production in the Sahel. An important farming system in the region is based on producing pearl millet and cowpea as staple crops, combined with the use of range and fallow lands for livestock keeping (Fernández-Rivera et al. 2004). Cattle, goats and sheep provide food and serve as a source of cash to purchase farm inputs and to cover expenses associated with the family wellbeing. They also provide manure, which is widely used as organic fertiliser to increase millet yields. Cattle, camels and equines provide draft power, especially for transport. With the exception of fattening animals, livestock feeding depends largely on grazing range, fallow and crop lands. Low soil fertility is a major constraint to primary production (van Keulen and Breman 1990), whereas poor nutrition is the main cause of poor livestock productivity (Powell et al. 1996).

This paper focuses on a case study on nutritional constraints to grazing ruminants in the millet–cowpea–livestock farming system of the Sahel. The variation in productivity and weight changes of cattle, goats and sheep is discussed in relation to seasonal fluctuations in feed supply. The paper describes feed availability, quality and use under village situations, the influence of land use and socio-economic factors on livestock nutrition and the response of cattle to nutritional management. Results of the case study are used to examine the relationships between causes, mechanisms and effects of nutritional constraints. We conclude the paper with a discussion of the seasonal variation in the nature of these constraints and an outline of alternatives to improve the nutrition of livestock in the system.

Study site, materials and methods

Study site

The case study was carried out in Banizoumbou, Tigo-Tegui and Kodey, three village lands located 60–90 km east of Niamey, Niger. The area is situated within the Fakara region and includes 10 communities that in 1995 were home to 492 households and 4946 people. In the same year the livestock population included 2624 cattle, 2684 sheep and 2144 goats. The annual rainfall is about 450 mm distributed between June and September. The soils are sandy and generally of low fertility. These village lands were the subject of a comprehensive study on livestock mediated nutrient transfers (Hiernaux et al. 1998). They were selected to represent a wide range in the proportion of land under cultivation (30% in Banizoumbou, 36% in Tigo-Tegui and 62% in Kodey in 1995) and the most common socio-economic and agro-ecological characteristics of crop–livestock systems in the Sahel. A detailed description of the study site was presented by Hiernaux and Ayantunde (2004).

Farmers in the area depend on crop–livestock production. Pearl millet is the staple food and is cultivated either alone or intercropped with cowpea. The herds include mixes of variable numbers and proportions of cattle, sheep and goats and lower numbers of equines and camels. Ruminant livestock graze either freely or supervised by herders, the latter being the most common practice, especially for cattle. Cattle, sheep and goats are generally corralled during the night to collect manure in fields scheduled for cultivation the following cropping season. With the exception of some lactating cows kept on the homestead for the provision of milk and animals unable to walk long distances, cattle are taken on transhumance to the pastoral zone at the beginning of the rainy season and returned to the cultivated zone when millet and cowpea are harvested. Once back in the cultivated zone the herds are taken to graze millet residue fields in intensely cultivated areas before returning to the village lands.

Survey on household characteristics

Surveys were conducted involving 542 households in the three village lands to characterise the production system in terms of socio-economic indicators and resource management strategies in relation to nutrient use and flows (Hiernaux et al. 1998). This paper presents information on cropped area and herd size and composition.

Survey on herd productivity

Herd management and transactions of animals were monitored in 434 herds during 1995–97. This monitoring provided basic information on reproductive performance (birth rates) and mortality of cattle, sheep and goats. Offtake (sales, gifts etc.) and purchases of animals were also recorded.

Feed availability

Between 1994 and 1998 the amount of plant biomass available on rangelands, fallows and cropland was measured every year at the end of the growing season in the three village lands. Aboveground forage mass was also estimated in 1995 and 1996 along the grazing itineraries of two experimental herds, one of cattle and one of sheep and goats in Boundou, a community within the village land of Banizoumbou.

Experimental herds in Boundou

Between 1994 and 1997, sets of animals including 8 intact, 6 ruminally fistulated and 4 esophageally fistulated males of each of three species (cattle, sheep, goats) were kept in Boundou. Cattle and small ruminants were kept in two separate camps, herded by two different herders and grazed separately within the same village land. Managing these animals followed practices common to the majority of animals in the study site. They were corralled overnight for 11–13 hours to collect manure and were given water once daily. They received no feed supplement other than mineral licks. As the intact sheep and goats reached their mature weight after 2 years of the study, they were replaced by a set of young animals. Nutritional indicators were measured as described below.

Weight changes, diet quality, forage intake and rumen function

The live weight of the intact animals in the two herds in Boundou was determined monthly by weighing them for 3 consecutive days following about 12 hours of overnight fasting. Extrusa samples were collected monthly from the esophageally fistulated animals and analysed for crude protein (CP) and *in vitro* organic matter disappearance (OMD). On 15 occasions between July 1994 and August 1996, faecal excretion was determined during 10 consecutive days in the intact animals using collection bags made of canvas. Intake of digestible organic matter per unit of metabolic weight ($kg^{0.75}$) was estimated from faecal output, OMD and live weight (W, kg) of the animals. Feeding behaviour and water intake (results presented elsewhere) were also assessed in the intact animals. Rumen fluid samples were taken from intact animals every month during three days in the morning before grazing, at noon before watering and in the afternoon after returning from grazing. The rumen fluid was analysed for ammonia concentration (NH3-N). A standard forage (bush hay with composition in g/kg dry matter for crude protein (CP) = 28, neutral detergent fibre (NDF) = 753, acid detergent fibre (ADF) = 509, lignin = 106, and phosphorus = 2.5) was incubated *in sacco* at several seasons for 8, 16, 24, 32, 48, 72, 96 and 120 hrs in the rumen of the fistulated animals. This information was used to estimate rates and extent of disappearance of NDF.

Feeding behaviour

Feeding behaviour was assessed in 10 herds grazing in the 3 village lands (Banizoumbou, Tigo-Tegui and Kodey) in 1995–96. The foraging activities and the location of animals were observed and registered every 5 minutes. The distances walked were estimated by overlaying the grazing itineraries on a Geographical Information System constructed to describe land use. This geo-referenced database included a complete mapping of land units for cropped land, fallows and range of the three village lands.

Improving nutrition through supplementation and grazing management

Monitoring the nutritional status of animals in Boundou was followed by a series of experiments to assess ways to improve livestock nutrition. Effects of night grazing and supplementation were studied in two experiments (Ayantunde et al. 2001). Because of difficulties in controlling the sources of variation under village situations, these two experiments were carried out in the ranch of Toukounous, which is situated about 200 km north-east of Niamey.

In Boundou, Sangaré et al. (2002a) assessed the influence of supplementation on weight changes of cattle and its interaction with mulching on soil fertility and millet yields.

Fernández-Rivera et al. (2003) conducted an experiment in the villages of Katanga and Gouro-Yena to assess the effect of seasonal transhumance and dry-season supplementation on average daily gains and annual weaning rates of cows. These two communities are located within the village land of Tigo-Tegui. In 79 cows that calved between 1999 and 2001, milk offtake (consumption by calves excluded) was determined using 6.3 ± 2.9 records per cow per lactation.

Socio-economic, institutional and policy influences on livestock nutrition

Studies described above address generally the effects of feed availability and herd management on livestock nutrition. Nutrition of livestock is also influenced by socioeconomic and policy factors that act at the level of individual farms, local communities and countries (Williams et al. 1997). Therefore, we include a discussion on these factors as they affect the nutrition of livestock in the study area and, in general, in the Sahel.

Results and discussion

Characteristics of farms in the study area

Two types of producers, namely village farmers and camp farmers, co-exist and interact in this farming system. They contrast by the relative importance of livestock keeping and cropping (Table 1). The village farmers are sedentary and have the traditional right to the land for cropping. They have very few ruminant livestock (1.34 ± 0.18 Tropical Livestock Units (TLU, 1 TLU = 250 kg W). Only 9% of them have more than 5 TLU. The camp farmers, on the contrary, are settled in camps scattered around the villages. They have larger herds (10.8 ± 0.6 TLU on average) and 45% of them manage more than 5 TLU. The village farmers cultivate more land area than the camp farmers. While part of the family of camp farmers remains in the camps year long, other family members move the herds to the pastoral zone of the drier northern Sahel when the rains start, and return them to the cultivated zone after grain harvest.

Table 1. *Characteristics of farms in the study area (1995).*

	Village farmers	Camp farmers
Farms (no)	366	166
Persons/household (no)	9.1	9.6
Land cropped (ha)	14.5	10.5
Land manured (ha)	1.4	4.7
Herd size, heads per household		
Sheep	2.2	19.2
Goats	2.3	36.4
Cattle	3.4	27.6
Milking cows	0.6	5.8

The two groups of producers engage in exchanges of goods and services. These generally involve purchase of food and contracts to regulate access to land and fodder and exchange of manure. Camp farmers also take animals owned by village farms on transhumance on a contract basis. Conflicts may arise due to difficulties in moving herds, accessing grazing resources and damages to crops due to grazing.

Herd productivity

Some indicators of reproductive and productive performance of cattle, sheep and goats obtained from the surveys are given in Table 2. Annual birth rates for cattle, goats and sheep were 18.5, 40.2 and 36.1%, respectively. The birth rate for cattle falls within the range of 3–20% reported by Wilson (1986) for central Mali. Most births occurred towards the end of dry season (May and June). Mortality rate observed in cattle herds (1%) in the study area was low compared to 5% reported for central Mali (Wilson 1986). However, mortality in cattle herds can be as high as 40% (Wilson 1986). The mortality rates observed in goats and sheep were comparable to those reported by Colin de Verdière (1995) for the Filingué region of Niger. Sales often take place to meet family needs for cash. The offtake (sales) of 6% for cattle found in this study is similar to the 7% offtake reported by Wilson (1986) for central Mali.

Table 2. *Productivity parameters of grazing ruminants in western Niger (1995–97).*

Item	Cattle	Goats	Sheep
Herds (no)	169	112	146
Birth rate[a] (%)	18.5	40.2	36.1
Mortality[b] (%)	1.0	4.1	5.2
Sales[c] (%)	5.9	28.3	15.6
Purchases[c] (%)	3.0	14.6	5.9

a. Birth rate is calculated as ratio of births to adult females in the herd.

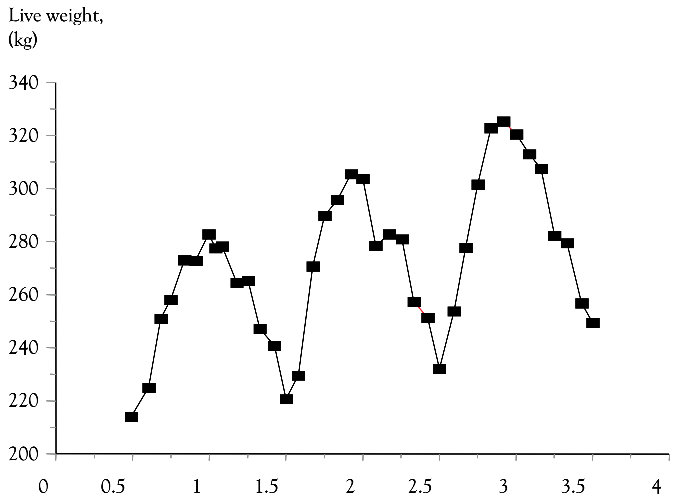
b. Mortality is the ratio of recorded death to the total number of animals in the herd.

c. Selling and buying rates are ratios of animals sold or bought to the number of weaned animals.

The average daily milk offtake from the 79 cows in Katanga and Gouro-Yena was 1.12 ± 0.556 l/day. This level of offtake, although low, falls within the common range in the Sahel of 0.5–5 kg/day (Wilson 1986) and is similar to that observed by Colin de Verdière (1995) in the Fillingé region in Niger. Fifty-one percent of these cows calved between May and July. With the estimated level of milk offtake per cow and the number of milking cows during the course of the year, milk availability at the household level was estimated at 0.7 and 6.5 l/day for the village and camp farms, respectively.

Body weight changes as indicators of the extent of undernutrition

Cattle showed a regular pattern of body weight changes consisting in gains of 80–100 kg during about 6 months (July to December) followed by a loss of 60–80 kg during about 6 months (January to June) with a net weight gain of about 20 kg per year, whereas small ruminants showed much shorter periods of losses and relatively higher weight increases per year (Figure 1). The live weight changes followed closely the pattern of availability of forage (see below) and this was more notorious in the case of cattle.



Cattle

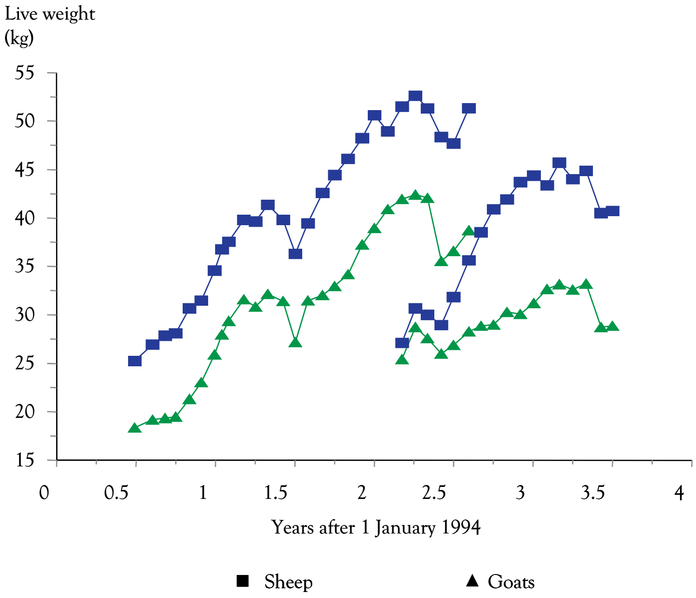


Figure 1. *Live weight changes of cattle, sheep and goats over three years in the village of Boundou in western Niger.*

In the two herds in Katanga and Gouro-Yena, the weight loss of non-lactating, non-gestating cows in the dry season varied between 380 ± 13 and 258 ± 16 g/day (Fernández-Rivera et al. 2003). Other studies showed that during the wet and post-crop harvest seasons, grazing cattle can gain up to 500 g/day (Ayantunde et al. 2001) and an average annual live weight gain of 50 kg (Schlecht et al. 1999b). In the late dry season and the transition period from the dry to the rainy season, cattle can lose as much as 300 g/day. Schlecht et al. (1999b) reported up to 22% body weight loss in non-supplemented cattle during the dry season. These results demonstrate the impact of the drastic seasonal fluctuations in feed supply and quality on the development of body weight.

Forage availability

Results on forage mass available on rangelands, fallows and crop residues during October 1994 and June 1995, averaged for the three village lands, are presented in Table 3. The standing herbage was characterised by marked inter-annual fluctuations. For instance, in Banizoumbou, standing herbage was 1298 and 733 kg/ha of dry matter (DM) at the end of growing season of 1994 and 1995, respectively. By the end of dry season, the standing herbage had declined significantly to 225 and 113 kg DM/ha, respectively. The end of growing season for herbage also coincided with peak of availability of millet stover. Moderate to high amounts of millet stover were available in all villages from harvest time to February (middle of the dry season), but the last 3 months (April to June) of dry season were characterised by a remarkable feed scarcity.

Table 3. *Seasonal fluctuations in standing herbage, weed and millet stover mass (kg DM/ha; mean ± sem) in three villages of western Niger (B = Banizoumbou; T = Tigo Tegui; K = Kodey).*

	Herbage on range			Weeds on cropland			Millet stover on cropland		
Village	B	T	K	B	T	K	B	T	K
Oct 94	1298±39	1303±56	1024±57	107±1	108±2	114±1	1461±40	1519±56	1475±52
Feb 95	502±61	615±95	586±121	63±14	70±12	70±9	802±155	813±184	958±100
June 95	225±13	237±15	111±9	48±5	50±5	21±4	346±70	364±84	421±48
Oct 95	733±24	838±37	820±31	172±5	208±12	188±5	1600±35	1625±46	1541±52
Feb 96	373±55	382±74	396±100	104±9	105±15	102±5	532±109	557±126	606±93
June 96	113±6	79±4	70±4	25±1	23±1	27±1	229±26	215±26	191±22

The aboveground plant mass in 1995 and 1996 along the grazing itineraries of the experimental cattle and small ruminant herds in Boundou is shown in Figure 2. Only from September to December the herds were grazing areas with more than 1000 kg DM/ha of plant aboveground mass. At the end of the dry season and beginning of the rainy season, the total plant DM was only about 200 kg/ha. These levels of forage availability result in extended grazing times, which lead to higher energy expenditures for walking (Schlecht et al. 2003), and in excessively low consumption rates per hour (Ayantunde et al. 2001). Thus animals are not able to consume forage as per their physical capacity.

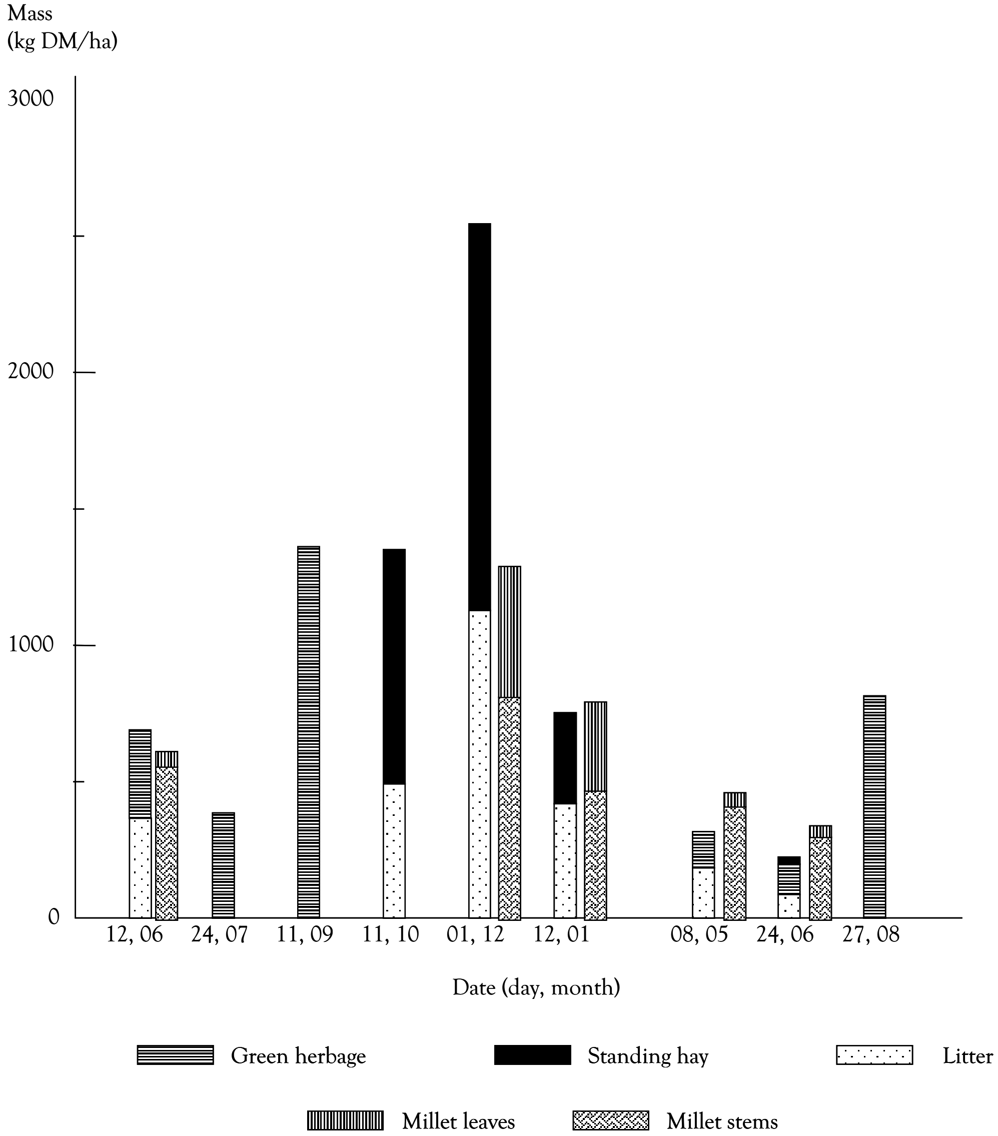


Figure 2. *Forage availability along grazing itineraries of cattle in 1995 and 1996 in the village of Boundou, western Niger.*

The herbaceous layer of Sahelian rangelands is generally characterised by a low plant density of the dominating annual graminae (Glatzle 1992). The productivity of natural rangelands is more strongly limited by lack of nutrients than by lack of water (Breman and de Wit 1983). Rangeland production is characterised by seasonal and inter-annual variation, but also by a large spatial variation in specific locations (Hiernaux 1996). Mean primary production ranges from 600 kg DM/ha in the northern Sahel with 200 mm of annual rainfall to 2400 kg DM/ha in the southern Sahel with 600 mm. The wide local variation in herbage production is explained by variation in soil type, rainfall distribution, runoff water patterns based on topography and geomorphology, and botanical composition of the herbaceous layer. As explained below, pastures may become inaccessible due to fragmented cropping and/or the expansion of dry season gardening in low-lying areas. Browse is important as animal feed, especially in the late dry season. The average annual foliage production of browse is approximately 150 and 50 kg DM/ha in the southern and northern Sahel, respectively, which is less than one-tenth of the average annual production of herbaceous layer (Glatzle 1992). In many locations the significance of browse as animal feed appears to be lower than is widely assumed. Availability of herbaceous and browse forage is greatly affected by drought. Prolonged and widespread drought results in dramatic reduction of forage yield and changes in plant species composition (Hiernaux 1996). Lack of feed and water ultimately leads to livestock mortality and changes in herd composition. In general, cattle are much more affected by drought than small ruminants, particularly goats (Powell et al. 1996).

Forage quality

Large seasonal changes in nitrogen (N) and phosphorus (P) concentrations in herbage and millet residues were observed in Boundou (Figure 3). The peak values of N and P in the standing herbage corresponded with the vegetative stage (around August) after which the nutritive quality declined rapidly. After the rapid fall, the feed quality, especially of grasses, remained constant and excessively low for most of the dry season. Results from analyses of extrusa samples collected in the same village from the esophageally fistulated animals are presented in Figure 4. Because of the selective behaviour of grazing ruminants, the protein content and digestibility of diets selected by esophageally fistulated animals were normally higher than those of the herbaceous standing mass.

Variation in CP and OMD (Figure 4) indicated both seasonal and inter-annual fluctuations in feed quality, with the highest values in the wet season and the lowest at the end of the dry season. Small ruminants tended to select a diet of better quality than cattle. However, Ayantunde et al. (1999) showed that cattle grazing Sahelian rangelands also exhibit a high degree of diet selectivity. Animals prefer some specific foraging locations and plant species, while avoiding others. This selection is also exhibited among plants parts (leaves, stem, seed and fruit). Breman and de Wit (1983) observed that zebu cattle selectively grazed a diet 2–5% higher in CP than that of the standing mass. The results of their study suggest that supplementation in the dry season with energy and or protein-rich feeds needs to consider the selective foraging behaviour of the grazing ruminants and the differences among animal species for optimal benefits.

Feed quality of the herbaceous layer in Sahelian rangelands tends to be inversely proportional to rainfall (Breman and de Wit 1983). In the southern Sahel, where nitrogen is more limiting than water, the crude protein (CP) content of herbage declines rapidly to values of 3–6% by the end of the growth cycle whereas in the north where water is the growth-limiting factor, herbage may contain up to 12% CP at the end of growth cycle (Glatzle 1992). There is thus a strong difference between north and south in the nutritional quality of Sahelian rangelands. Nutritional quality varies among plant species, but the variation within a species class (grass, legume and non-legume) is lower than between classes, that is, grasses and forbs (Ayantunde et al. 1999). Millet residues are on average of lower quality in terms of N and P content than the standing herbage.

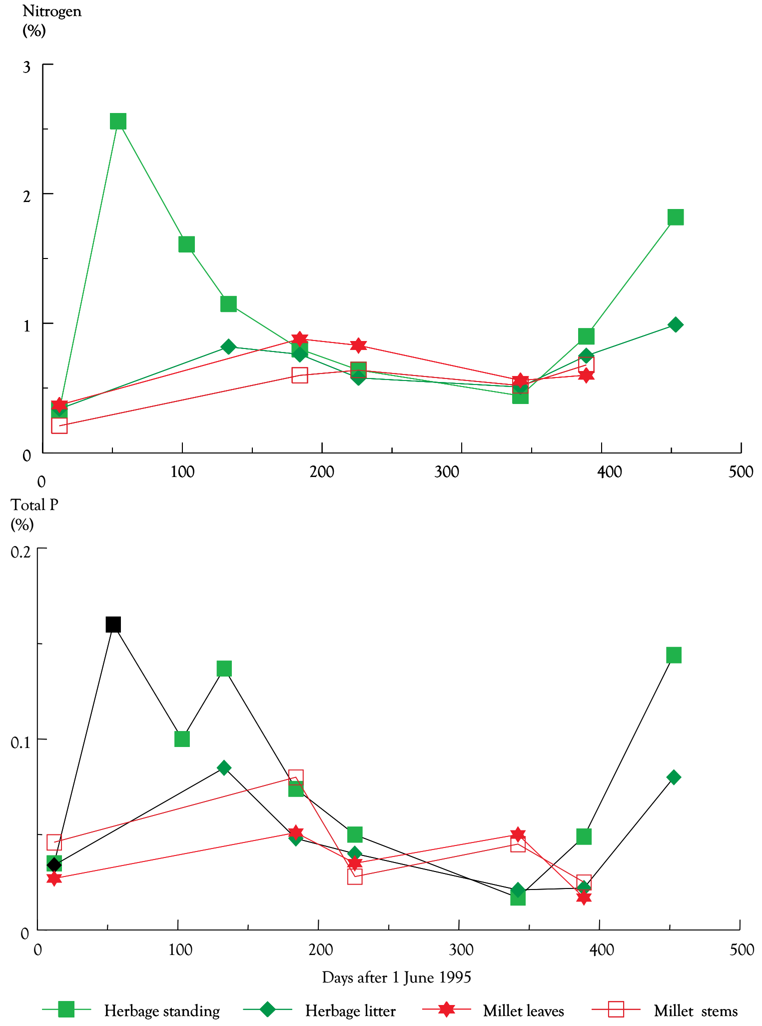


Figure 3. *Seasonal changes in nitrogen and phosphorus concentrations in herbage and millet residues in Boundou, western Niger.*

Forage intake

Results on daily intake of digestible organic matter (g per kg of $W^{0.75}$) by cattle, sheep and goats observed in Boundou are presented in Figure 5. Small ruminants had higher digestible organic matter intake (DOMI) per unit of metabolic weight than cattle. In cattle, DOMI ranged from 15–35 g/kg $W^{0.75}$ per day whereas values for sheep and goats ranged from 20–55 and 8–45 g/kg $W^{0.75}$ per day, respectively. The peak values were observed in the rainy and post harvest seasons when forage availability was relatively high and the animals also had access to harvested millet fields. The decline in DOMI as the dry season progressed is the response to the decrease in feed availability and quality. However, forage intake in the early dry season (harvest season) when animals have access to harvested millet fields in addition to the natural pasture can be higher than in the wet season. The body weight changes of small ruminants (Figure 1) followed a similar trend than that observed for DOMI (Figure 5). The DOMI observed in cattle were much lower than values of 30–50 g/kg MW per day reported in other studies in the Sahel (Schlecht et al. 1999a; Ayantunde et al. 2001). Intake values for cattle, especially during the season of high quality and abundant forage in 1995, were extremely low, possibly underestimated as result of excessively low estimates of faecal output.

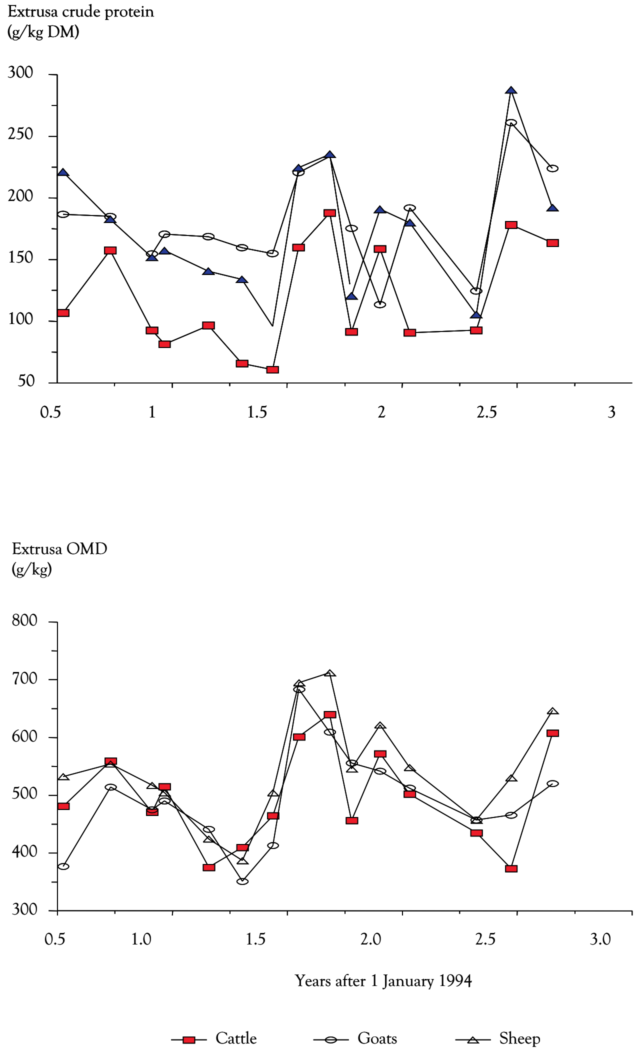


Figure 4. *Crude protein and organic matter digestibility (OMD) of extrusa selected by cattle, sheep and goats in Boundou in western Niger.*

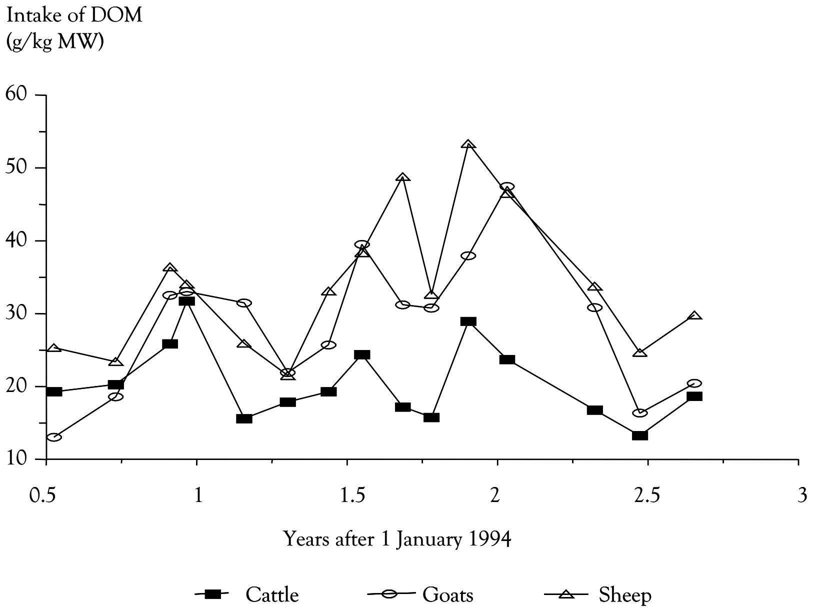


Figure 5. *Intake of digestible organic matter (DOM) by cattle, sheep and goats in the village of Boundou in western Niger.*

Rumen environment and function

During most of the year, the NH_3-N concentration in the ruminal fluid was lower in goats than in sheep, and cattle had lower ruminal NH_3-N concentrations than small ruminants (Figure 6). Concentration of ammonia in the rumen fluid of cattle was less than 70 mg/l for most of the dry season, whereas in small ruminants it did not appear to limit rumen function at any of the sampling times. These results are similar to those observed in cattle, sheep and goats grazing rangeland and crop residues fields in Sadoré, Niger, about 100 km south-west from the study site (Fernández-Rivera 1994; Powell et al. 1996). In the present study, large seasonal variations in *in sacco* NDF disappearance rates were observed (Figure 7). Cattle tended to have lower NDF disappearance rates than sheep, possibly because of the lower protein content of the ingested diet and consequently reduced ruminal NH_3-N levels. In spite of the high protein concentrations of their diets, goats had lower NDF disappearance rates than sheep, possibly due to consuming tree leaves high in tannin content. The most common tree in the range and fallow lands across the study sites (and broadly distributed in the Sahel) is *Guiera senegalensis*. The leaves of this tree are poorly digested and contain high levels of tannins (Zoulaideni 1994).

The present results illustrate that the environmental conditions and the digestive microbial activity in the rumen of cattle, goats and sheep grazing year-round on crop residues and rangelands vary seasonally and that at the end of the dry season they appear to be sub-optimal for fibre digestion and microbial growth, especially in cattle. The differences in rumen NH_3-N levels and extent of fibre degradation across species are likely the consequence of differences in feeding behaviour and type and quality of forage consumed.

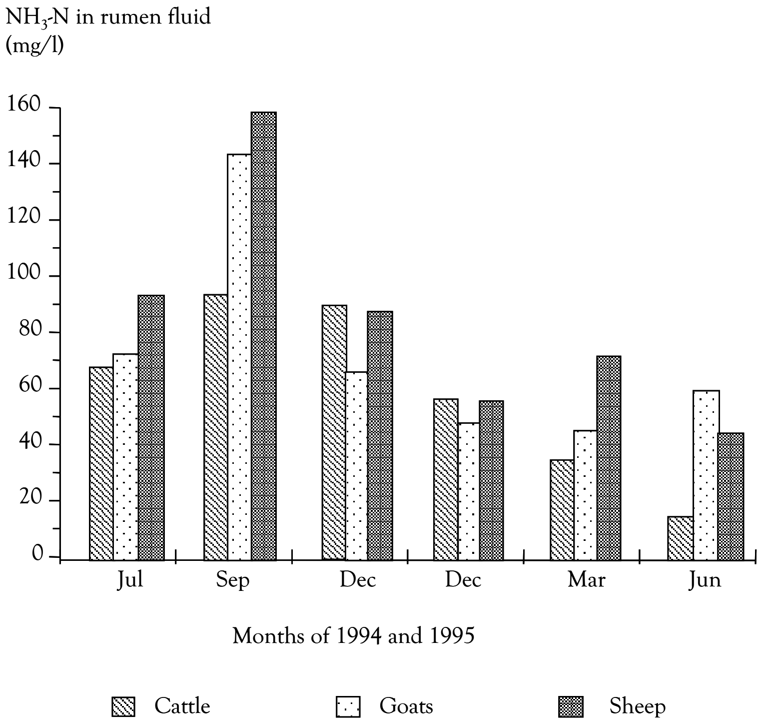


Figure 6. *Seasonal changes in ammonia in rumen fluid of cattle, sheep and goats in western Niger.*

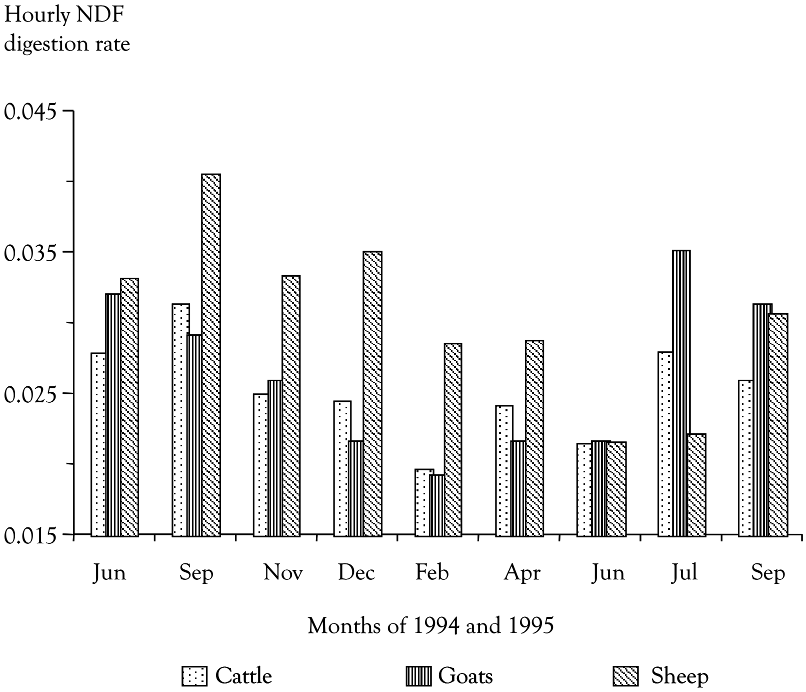


Figure 7. In sacco *disapperance rates of neutral detergent fibre (NDF) in cattle, sheep and goats in the village of Boundou, in western Niger.*

Herd management and undernutrition

Herd management can affect access to grazing land, and length and spatial orientation of grazing itineraries, time allowed for grazing, frequency of watering and access to crop residues. This case study assesses the effects of transhumance, corralling or night grazing and supplementation.

Transhumance

Transhumance is a common practice in the West African Sahel. It is based on more or less regular seasonal migrations from a permanent homestead. The motives for seasonal herd migration include access to better range resources in terms of quality and plant species diversity and protection of crops from damage by grazing ruminants (de Leeuw 1984). The animals are normally taken on transhumance to the pastoral zone of the northern Sahel during the rainy season. By moving north, higher quality forage and different species mixtures are obtained. The wet season grazing areas are also the location of sites for the 'cure salé', a practice of taking animals to lick soil in specific locations. This practice is believed to cover certain mineral deficiencies and act as a purge ridding stock of endo-parasites. Herd size is often positively related to degree of mobility (de Leeuw 1984).

In the study on transhumance of cattle conducted with the two herds in Katanga and Gouro-Yena, the animals covered 347 km in going on and returning from transhumance in the northern Sahel (Figure 8). The transhumance took about 100 days, which covered the growth period of crops in the south. Seventy-eight days were spent grazing in the north (Figure 8). When the animals returned from the long transhumance to the north at the time the millet fields were harvested, they were taken again onto a shorter transhumance to graze crop residues in the cultivated zone. The distance covered during the short transhumance was 86 km and it only lasted for about one month. Results from the study on both long and short transhumance showed that cows in transhumance tended to gain more weight during the post-harvest season than those under sedentary system (435 ± 23 vs. 383 ± 22 g/day, Fernández-Rivera et al. 2003). These studies showed that transhumance of cattle complements feed resources between the cultivated and pastoral zones. It is an adaptive strategy to cope with feed scarcity, in that it enables livestock holders to subsist and exploit the grazing resources of the pastoral and cultivated zones.

Night corralling versus night grazing

Common herd management practices in the Sahel such as herding mode (shepherding or free ranging), night grazing, watering and corralling affect time available for grazing by the animals. By corralling livestock directly on fields overnight after daytime grazing, the nutrients in faeces and urine, especially nitrogen and phosphorus, are deposited on the croplands (Powell et al. 1996). These manuring practices result in a net transfer of nutrients from rangelands and fallows to croplands. Though corralling to collect manure is an important soil amendment strategy in the Sahel, it is at the expense of the animals' need to graze in the night, especially during the dry season. When the animals are used to deposit manure in the crop fields, conflicts arise between the need for animals to graze long enough to have adequate feed intake and the need to improve soil fertility of the arable land.

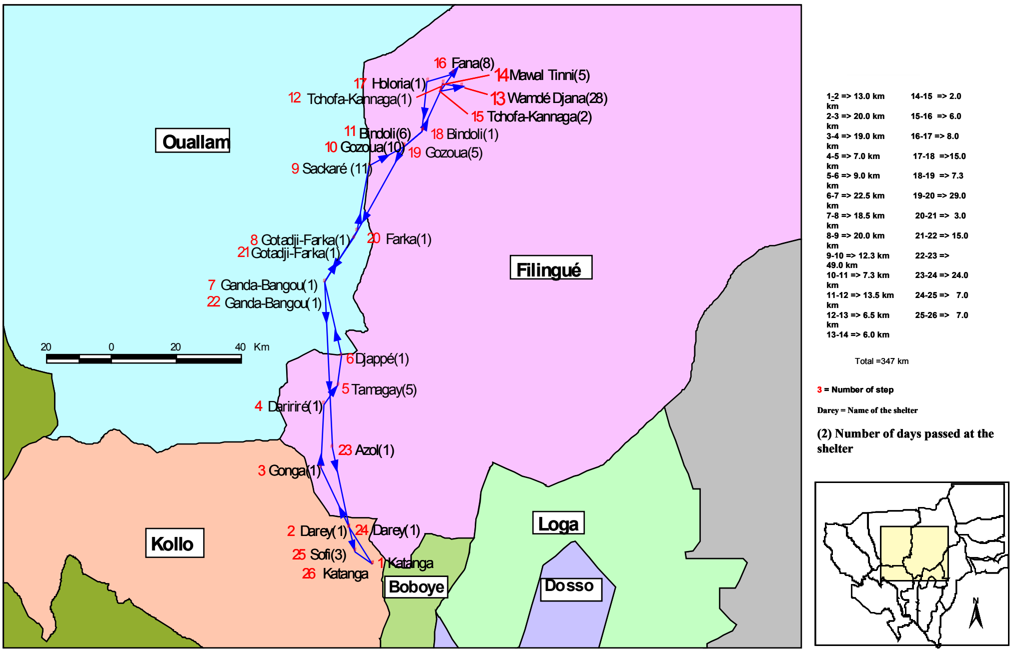


Figure 8. *Transhumance of a herd from Katanga to the pastoral zone during the rainy season of 1998.*

The experiments conducted in Toukounous showed that additional grazing time in the night is particularly important to cope with feed scarcity in the dry season. Night grazing provided the advantage of increased grazing time, which resulted in increased forage intake and better animal performance in terms of live weight gain (Ayantunde et al. 2001). The value of night grazing varies with environmental and pasture conditions and production objectives. Grazing exclusively in the night cannot be a substitute for day grazing. It complements day grazing and leads to better animal performance, especially in the late dry season.

Supplementation

Supplementing grazing ruminants in the study site is often limited to animals of high nutrient demand, such as those in lactation, mostly during the dry season when available forage is low and of poor quality. Use of feed supplements is common in fattening of sheep for the feast of 'Tabaski'. The experiment in Toukounous (Ayantunde et al. 2001) showed that the benefits of supplementation include increased digestible organic matter intake and better animal performance (Figure 9). Whereas the supplemented cattle gained body weight, the unsupplemented cattle recorded weight loss.

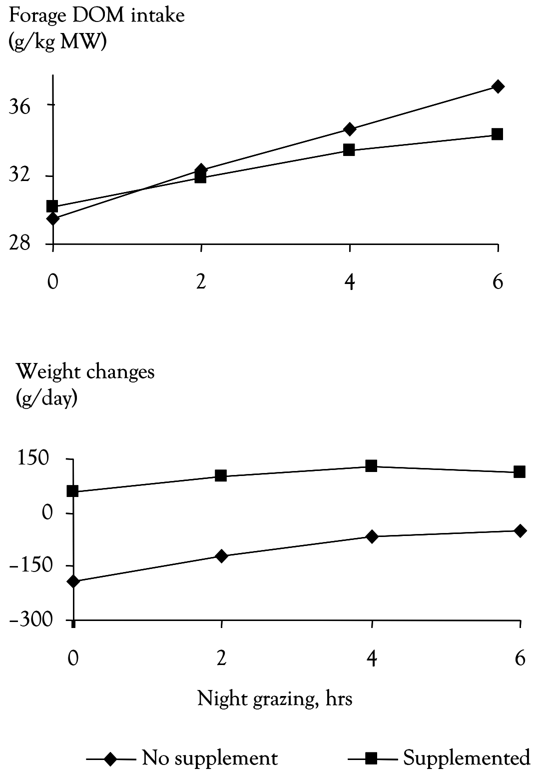


Figure 9. *Forage digestible organic matter intake and weight changes of supplemented and non-supplemented cattle grazing day and/or night.*

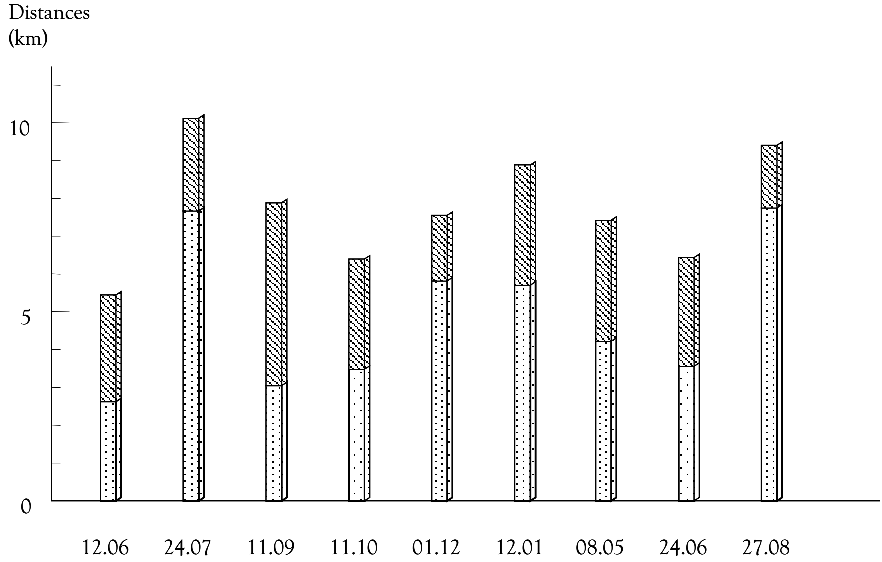
In the study in Boundou, supplementing cattle was shown to be beneficial not only to animals but also improved soil fertility (Sangaré et al. 2002a). These authors reported improvement in soil chemical properties (NH_4-N and soil pH) when associating mulching and corralling of supplemented cattle compared to the sole corralling. The effect of mulching and corralling on millet grain and stover yield was also higher when cattle were supplemented (67 and 50%) than when they were not supplemented (30 and 26%).

In the studies in Katanga and Gouro-Yena, it was observed that cows supplemented at the end of the dry season had lower weight gains during the rains than those that were not supplemented, and that supplemented cows had slightly better reproductive performance than those that were not supplemented (Fernández-Rivera et al. 2003). Therefore, analysis of profitability of use of supplements needs to consider the effects in the long term and include aspects such as mortality, reproductive performance and crop production if manure is used to fertilise the soil.

Influence of land use on livestock nutrition

Observational studies on the 10 herds showed that distance walked daily by grazing ruminants was longest during the wet season (Figure 10) when feed resources were plenty.

The reason for this is lack of access to grazing areas around the villages, since crops have to be protected from damage by the animals. More than 80% of the grazing time was spent on fallow and range land by the animals in wet season (Table 4). The associated energy cost in walking obviously increases the energy requirements of the animals.



Cattle

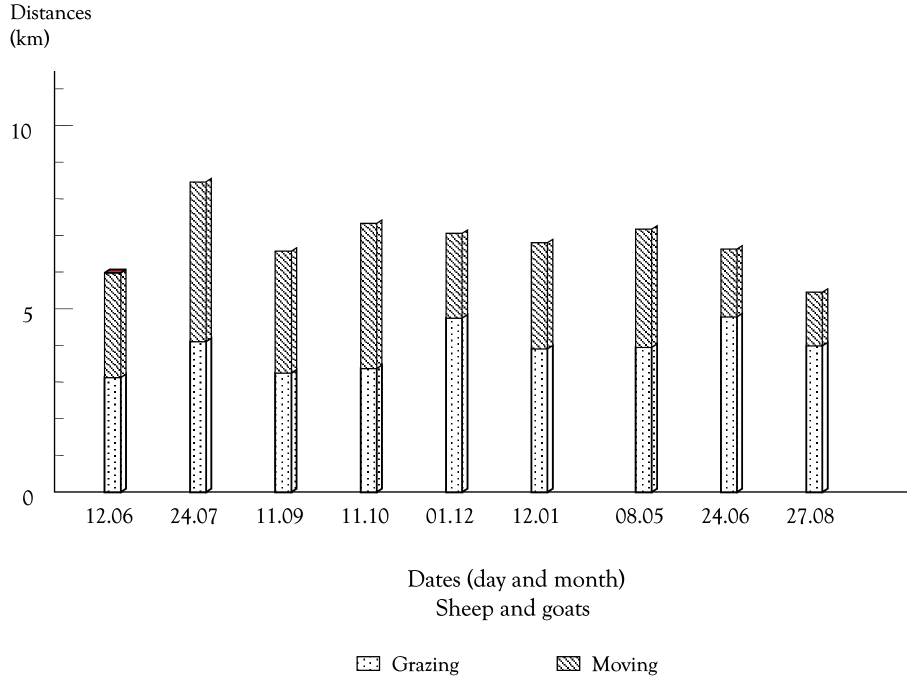


Figure 10. *Seasonal changes in distances walked daily by grazing cattle, sheep and goats in western Niger.*

Table 4. *Daily grazing time of cattle and small ruminants and its partition on activities and land units in two villages in south-western Niger.*

Season	Village	Herds (no.)	Grazing time (h/day)	Time (%) spent Eating	Time (%) spent Walking	Time (%) spent Resting	Time (%) spent on Cropland	Time (%) spent on Fallow/ range
Rainy	Banizoumbou	11	10.4	77.3	10.1	12.2	0.1	99.9
	Kodey	10	9.9	63.2	17.8	17.8	15.0	85.0
Early dry	Banizoumbou	12	9.7	78.1	6.3	14.6	59.6	40.4
	Kodey	14	10.9	62.0	15.6	21.2	80.4	19.6
Mid-dry	Banizoumbou	15	10.7	70.8	7.9	20.1	43.3	56.7
	Kodey	8	10.6	55.6	14.0	29.0	79.0	21.0
Late dry	Banizoumbou	4	11.2	65.1	6.1	27.7	47.2	52.8
	Kodey	7	11.1	54.6	14.5	29.2	88.8	11.2

Grazing time increased as the season progressed from wet to dry (Table 4). Eating time as a proportion of daily grazing time decreased from wet to dry season as the animals spent more time in search of food and for resting due to high ambient temperatures (>40°C) in the late dry season. Thus, where and when animals are allowed to graze should be taken into consideration in devising strategies to cope with feed scarcity.

Socio-economic and policy constraints on livestock nutrition

The use of feed resources in the study area, and in general in the Sahel, is limited by various socio-economic, institutional and policy issues. Rangelands, uncultivable lands and fallow fields in most part of the Sahel are common pool resources used simultaneously or sequentially by members of a community or a group of communities. Communities that possess primary use rights may allocate rights of access to subsidiary groups. For example sedentary farmers may give concurrent or sequential rights to grazing on village lands to transhumant pastoralists. These rights may shift over time leading to re-negotiating access rights or conflicts. Lack of clarity in access and use rights represents a major constraint to feed availability, especially for transhumant pastoralists in the Sahel. Even where use rights are clearly specified, the heterogeneity of users and multiple uses to which common pool resources are put suggest that co-operative action will be required to ensure equitable access to feeds by all farmers and to promote sustainable management of rangelands and fallow fields.

Demographic changes also have a substantial effect on feed availability from the range. Arable land expansion, partly due to high population growth, results in reduced rangeland area and seasonal inaccessibility to remaining pastures due to fragmentation caused by cropping low-lying areas previously used for dry season grazing. The net effect is a reduction in feed availability from the rangelands and the concentration of increasing numbers of livestock on smaller areas, which destroys pasture vegetation and contributes to range degradation. Land tenure and use policies are needed to facilitate herd mobility.

Land tenure security is also vital to investing in land-improving inputs, such as manure, if the productivity of both cropland and rangeland are to improve (Gavian and Fafchamps 1996).

The reduction in feed availability from range has been partly offset by increased availability of crop residues. In contrast to the wide variety of feeds available from the range, crop residues are seasonally produced. They become available only after grain harvest. Farmers use various methods to feed crop residues to their animals. Arranged in increasing order of labour requirements, these methods include: (1) open access to whole residues on harvested fields; (2) harvest and removal of stalks, with subsequent open access to stubble on harvested fields; (3) harvest and removal of stalks, with subsequent restricted access to stubble on harvested fields; (4) transport and storage for feed or sale; and (5) harvest of thinnings from cultivated fields for selective feeding before the main harvest (McIntire et al. 1992).

The pattern of crop residue use is often dictated by population density, crop residue value, herd management practices and level of transport and marketing infrastructure. Open access to residues occurs in areas with low population densities and where animals are herded communally. In densely populated and heavily stocked areas, farmers restrict access to crop residues. The availability of labour, large livestock populations and easy access to markets encourage the removal of crop residues from fields. Direct grazing, through either open or restricted access, allows farmers to use residues as feed without incurring storage and processing costs. This method of feeding results in low utilisation rates due to trampling and spoilage, but allows for the consumption of most nutritious plant parts and return of nutrients to the soil. Methods of residue feeding that involve harvesting (i.e. cut-and-carry systems) are more demanding in terms of labour, transport and storage facilities. The returns to these methods have to be reasonably high before they appeal to farmers. This is why in the region where the study site is located they are mostly used for high value crop residues such as cowpea and groundnut hay and for fattening animals or dairy cows raised in peri-urban areas with ready access to markets.

Apart from the socio-economic factors discussed above, there are other limitations to the use of local feeds in the Sahel. In the 1970s and 1980s, inappropriate pricing policies and overvalued exchange rates encouraged the use of imported grains and concentrates at the expense of locally produced feeds. After implementing economic policy reforms and liberalising the exchange rate markets in late 1980s and early 1990s, exporting agricultural products became profitable again. This has encouraged the export of agro-industrial by-products, such as cottonseed cake and groundnut cake, to the detriment of the livestock sector in most countries. The low availability and high cost of these supplements prevents their use at large scale. However, in the study area feed supplements derived from the daily processing of grains for human consumption are widely used and sold in local markets.

General discussion

Causes, mechanisms and effects of undernutrition

Nutrition of grazing ruminants in the millet–cowpea–livestock farming system of the Sahel is related to numerous factors. We argue that in this system, poor soil fertility and low rainfall, characterised by a high inter-annual variation and recurrent droughts (Hiernaux 1994), are the chief causes of poor nutrition of livestock. They limit the primary production of range and cropland and lead to drastic seasonal fluctuations in feed supply. The effects of feed scarcity and seasonality are exacerbated by poor feed quality, including the presence of anti-nutritional factors, which results in low feed use by the animal.

A key mediating mechanism that leads to poor productive performance is low forage intake. Low feed availability increases grazing time and, below certain levels of aboveground mass, reduces forage intake. Some herd management practices decrease grazing time and consequently limit forage intake. Other management practices increase energy expenditure in walking, further compromising the nutrition of grazing animals. Expansion of cropping lands at the expense of rangeland may result in higher overall feed yields but limits availability and access to other grazing lands during the rainy season. Land tenure and use rights also constrain the nutrition of livestock through limiting access to grazing lands and water and often lead to conflicts among users of these resources. A poor capital base and limited access to markets prevent the wide use of purchased supplements.

Seasonal variations in forage intake and quality and the higher energy expenditure due to long walking distances result in low availability and imbalances of nutrients at the animal, tissue and cell levels. From the mid dry season to the early rainy season, lack of feed is the overriding factor. It leads to low availability of all nutrients, primarily those yielding energy and protein. Nutrient imbalances are likely manifested as protein deficiencies from the peak of forage biomass and crop residues to early in the dry season, when fodder is still abundant and nutritional quality is decreasing. Late in the dry season insufficient levels of nitrogen and soluble carbohydrates in the herbaceous layer and the presence of anti-nutritional factors in browses impair rumen function and limit the ability of the animal to extract nutrients from the available feed. Minerals, especially salt and phosphorus, appear also to constrain the nutrition of grazing ruminants in the study zone. Sangaré et al. (2002b) observed a response to supplementation with phosphorus in growing lambs. The provision of water for livestock also constrains livestock nutrition in the system, especially during the late dry season. Issues related to water–livestock interactions in the study site are addressed in a separate paper.

The low availability and imbalances of nutrients lead to poor animal performance. Depending on the animal physiological status, nutrient deficiencies and imbalances result in growth retardation, reproductive wastage, low milk yield, increased susceptibility to disease, lower ability to perform work and lower amounts of manure. These effects on the animal negatively impact the ability of farmers to benefit fully from their herds. The ultimate consequence of poor livestock nutrition is lower income due to productivity losses and lesser sales of products; losses of assets and increased vulnerability to risk due to animal mortality; food insecurity resulting from lower farm productivity; and less sustainable farming due to a lower ability of farmers to recycle soil nutrients efficiently (Figure 11).

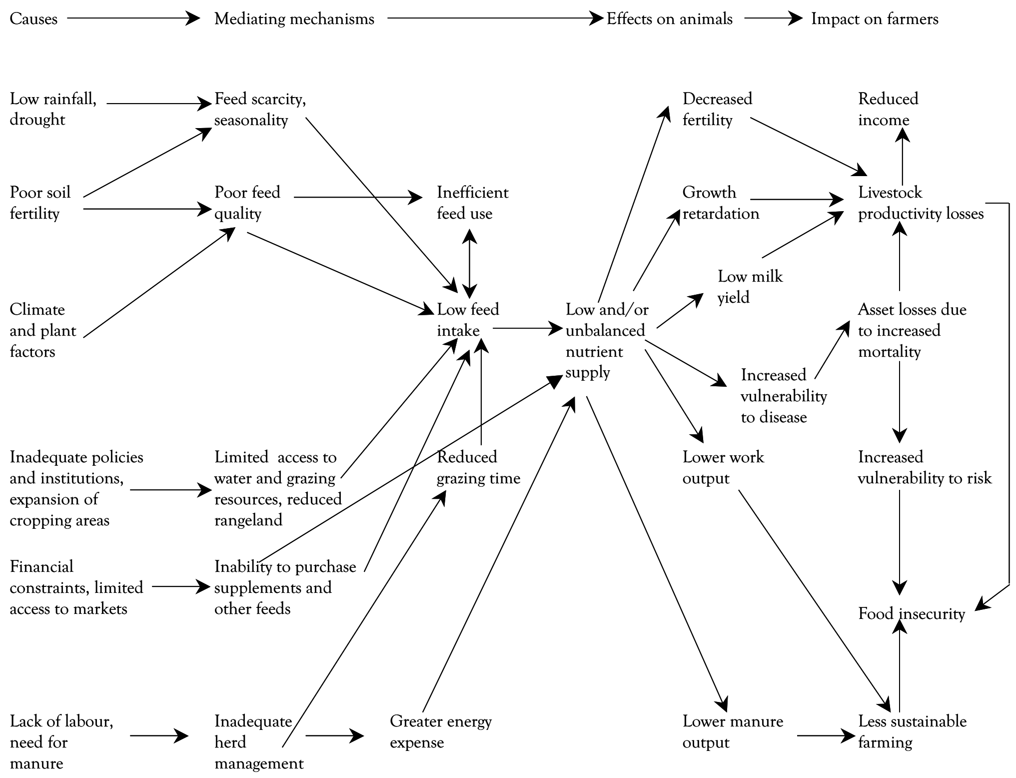


Figure 11. *Underlying causes, mediating mechanisms and effects of undernutrition of livestock at the animal and farm level in the millet–cowpea–livestock system of the Sahel.*

Most studies on undernutrition of livestock have focused on the effects of lack of feed on the physiology and production of the animal, but have failed to distinguish the underlying causes from their mechanisms and effects. This paper attempts to establish this distinction and examine how causes relate to mediating mechanisms and these lead to productivity losses, ultimately impacting on farmers' livelihoods.

Seasonal variation in the nature of nutritional constraints and opportunities to improve nutrition

The causes of undernutrition in livestock, and therefore the options to improve nutrition, vary seasonally. Late in the dry season lack of feed is the overriding factor and low protein content, especially in cattle, limits the efficient use of the feed available. The problem is compounded as the rains start due to spoilage of the remaining roughage, and occasionally, due to the direct effects of rains on animals. The main option during the late dry season and early rains, before the herds leave on transhumance, consists in providing supplementary feeding with crop residues, bush hay and/or grain by-products. If the amount of roughage available aboveground is extremely low, the rate of intake is very low and the animals spend more energy walking. Under these situations an alternative is to keep the animals tethered or in camps with survival feeding. Supplementary feeding with roughage will be determined by availability of labour and cost of transport, whereas use of concentrates will be a function of availability and cost of grain by-products.

As the rains continue, the forage starts to grow and the crops develop. At this stage the quality of the forage available is very high and the main constraint is herd mobility. Grazing and moving herds to watering points during this season may lead to crop damage and thus to conflicts between herders and farmers. The main option to improve nutrition and prevent conflicts in this season is the establishment or strengthening of local institutions to facilitate herd movements through corridors for herds to access range and watering points.

Except some trees that continue growing after the rainy season ends, all range forage and crops residues are produced during the rainy season. Attempts to increase fodder production on rangeland and/or cropland must be targeted during this season. Heavy continuous grazing during this season leads to undesirable changes in vegetation and lowers range productivity (Fernández-Rivera et al. 1995). There are opportunities for controlling the intensity and timing of grazing using short duration rotational grazing strategies by organising herders. Increasing the quantity and quality of fodder with food–feed crops is possible through precision manuring and applying fertilisers and possibly through variety selection. This option is less attractive if the residues are grazed communally, as is the case of millet stover. However, harvesting millet residues is becoming a common practice in the more densely populated areas. Cowpea hay is harvested and highly priced in local markets. It can be an option to supplement animals with higher protein requirements, such as lactating cows. However, because of the high demand for rams to slaughter in religious festivals, a more profitable use of cowpea may be for fattening sheep. Conserving crop residues and bush hay under cut-and-carry strategies may reduce spoilage and provide feed late in the dry season. Most of the growth, especially in cattle, occurs between June and December, from grazing on range and crop residues. During this period supplementation is not required. In on-station studies it was observed that growing sheep grazing on millet residues responded to supplementation with rumen undegradable protein (Salla and Fernández-Rivera, unpublished data). However, by-products of animal origin (e.g. blood and bone meal) are expensive and due to food safety concerns their use is increasingly restricted. Thus this option does not appear to be practical or economical.

In the early to mid dry season herd management appears the most practical option to improve nutrition. Calving generally occurs throughout the year and about 50% of the calves are born between April and July. It is common that calves older than 6–9 months continue suckling through the dry season. With demand for animals for fattening in the cultivated zone these calves could be weaned and sold along with cull animals before they lose weight. This would result in lower nutritional stress of otherwise lactating cows at the end of the dry season and in less pressure on the range during the rains. However, this strategy faces the conflict between the perceived advantages of increasing offtake and the need for storing wealth. Its application requires incentives and options acceptable to livestock keepers for investing the proceeds from selling animals. Night grazing can also be practised to improve nutrition during the early and mid dry season. Allowing animals to graze at night increases feed intake but reduces the amounts of manure collected.

As the dry season progresses, aboveground forage mass decreases. Animals require longer grazing times and spend more energy walking. Up to some point, the decrease in forage availability is compensated with longer grazing times. However, when forage availability is extremely low, such compensation is no longer possible. At this stage, if harvested crop residues or bush hay are available, it is advantageous to restrict walking by keeping animals on fields scheduled for manuring and feed these roughages or other supplements. The feed refusals are incorporated into the soil along with the manure and urine and contribute to improving soil fertility and increasing millet yields. As explained above, these options depend on the availability of labour for harvesting crop residues and bush hay, options to transport and store these roughages and on the cost of supplement feeds. In peri-urban areas with easy access to markets these supplements are increasingly being used to improve livestock nutrition.

This study points to the need for quantitative assessments of the impact of undernutrition of livestock on income, food security and assets at the household level. Such assessments would help identify priorities among the options for intervention described above, so as to better inform livestock development efforts in the millet–cowpea–livestock system of the region.

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Overcoming feed limitations in dual-purpose cattle system in Latin America

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Summary

In this paper, the dual-purpose cattle system is considered in detail. The relative importance and constraints, response to improvements in the feed supply and management and some proposals are given with respect to research and development needs.

Introduction

At the doorway of the third millennium, the population of Latin America is nearing the 500 million mark, of which 8% is in the agricultural sector (Ruiz 1993). Twenty-eight percent of the Latin American territory (nearly 600 million hectares) is under some form of pasture. Although Latin America accounts for 20% of the world's milk cows, the total milk output of the region is only 11.5% of the world's production (Table 1) (FAO 1997).

Table 1. *Milk production in the world.*

Geographical dimension	Total milk animals ($\times 10^3$ head)	Milk yield (kg/animal)	Total milk ($\times 10^3$ t)
World	227,674	2072	471,794
Africa	35,827	475	17,004
Asia	71,112	1229	87,412
Europe	59,142	3608	213,399
Latin America	45,728	1194	54,596
Tropical	40,320	249–3933	44,521
Temperate[1]	5408	1388–4081	10,075
USA and Canada	10,495	7515	78,872

1. Includes Argentina, Bolivia, Chile, Paraguay, Peru and Uruguay.

Source: FAO (1997).

The main reason for the low level of milk production is that in Latin America milk production is largely based on low-producing cows and/or insufficient or low-quality feed resources. Managing these resources requires human and capital inputs while the efforts to improve the production systems are influenced by policy, socio-economic, environmental and technological factors. Discussion on the interplay between these resources and factors is beyond the scope of this paper.

Latin America and the Caribbean possess abundant natural resources and various forms of livestock systems, which provide sustenance for the majority of farmers. Seventy-six percent of the agricultural land is used for grazing (Ruiz 1997); the use of this resource allows the region to produce 39% of the world beef (Table 1) and nearly 12% of the world's milk volume.

Milk production in the region is associated with two agro-ecological zones: the highlands and the lowlands (Seré 1983; Holmann 1990). The highlands (1000 to 3500 metres above sea level) contain temperate grasses and legumes, which support cattle of European extraction, used in specialised dairy systems and require more precise and developed technology. The lowlands can be subdivided into two ecozones based on the annual rainfall— the dry lowlands (600–1000 mm) and the humid lowlands (1000–5000 mm). The dry lowlands may have up to seven months of drought while the humid lowlands may not experience any dry season, but when it occurs it usually lasts for only three weeks.

Due to high temperature (27°C) and humidity, grasses in the lowlands grow rapidly but their poor quality is one of the factors responsible for low animal productivity. Ticks and tick-borne diseases, and climatic conditions have led to the use of hardy breeds such as *Bos indicus* and Creole cattle in the lowlands. Introducing European breeds to this stock have helped to develop the so-called dual-purpose production systems.

Three major commodity-driven cattle systems are practised in the region: beef cattle production (commonly in the hands of farmers practicing extensive ranching); specialised dairying which is based on capital-intensive resources and technology (using specialised breeds of cattle) and is usually located in temperate climates supporting high-quality forages; and the dual-purpose cattle systems in which both beef and milk are considered to be of similar importance, either for consumption by the farmer's family or to supply the local markets. This latter system is associated with small farmers who also plant crops (Ruiz 1993). These farmers contribute up to 26% of the total beef and 50% of the total milk in tropical Latin America, according to Janssen et al. (1991).

In the following sections, the dual-purpose system is considered in detail. Its relative importance and constraints, response to improvements in the feed supply and management and some proposals are given with respect to research and development needs.

Dual-purpose cattle system

From 15th to the end of 19th century, cattle in Latin America were managed in an extensive, rather primitive and traditional way. Grazing was the primary form of feeding, taking advantage of savannahs and natural prairies. The animals were of Spanish origin and gradually adapted to the tropical conditions. At the beginning of the 20th century, the livestock production systems were 'modernised' as illustrated by importing specialised breeds such as Jersey, Holstein, Brown Swiss, introducing better pasture species and rotational grazing, the use of installations, provision of water, and other improvements (Castillo 1992).

However, the 'modernisation' process revealed that the imported stock of European cattle had serious limitations under tropical conditions, in view of the mismatch between the available forage quality and the animals' nutritional needs. The seasonal fluctuations of available forage, lack of access to credit and technology by the rural farmers and the poor market infrastructures and incentives also limited the performance of exotic breeds. As a result, reproductive efficiency, milk production and survival in herds of European extraction were negatively affected (Plasse 1992).

The crossbred cows from zebu and Creole even showed modest but superior performance compared with the European cows. However, the scientific community who were more inclined to pursue maximising production along their strict disciplinary lines largely ignored this fact. In addition, due to the linkage of the often genetically undefined animal with the poor, resource-limited farmer, most researchers, ranchers and politicians simply ignored this emerging milk-and-beef cattle system considering it synonymous with backwardness and underdevelopment. This perception justified allocating research resources to the other cattle systems (Seré 1989), which, in turn, led to recommending technologies inappropriate to the dual-purpose system. Unsurprisingly, dual-purpose cattle farmers rejected these recommendations as they perceived high risks and low economic returns whereas the scientific community viewed the lack of adoption as a proof that the dual-purpose systems offered little potential for technological improvement (Wadsworth 1995). It was not until the mid-1970s, when a new holistic philosophy began to take hold in the scientific community that attention was given to the dual-purpose system.

Defining dual-purpose system

The dual-purpose system provides the two most important commodities from cattle: milk and beef. These products are supplied by separate beef and dairy cattle systems but with strong bias in favour of one product or the other. Developing the dual-purpose cattle system was a response to the rationale of the small farmers not to rely on only one product. This reflects their strategy to minimise the risk of economic disaster due to a drop in prices, or attack of plagues or diseases were they to be a monoculturist.

Wadsworth (1995) classified cattle systems based on the proportion of the gross income derived from the two main commodities. For example, a beef production system would be one where at least 75% of the gross income is obtained from the sale of animals; a dairy production system should yield 75% of the total gross income from the sale of milk; and the dual-purpose system would allow incomes below 75% of the total in any one of the two products.

A descriptive definition of the dual-purpose system would be the following: A traditional cattle system prevalent in the American tropics, which is based on grazing and the use of hardy mixed-breeding animals, where both milk and beef production are the primary functional objectives, and where cows are milked with the calf at the foot and weaning usually takes place when lactation is over. Dual-purpose cattle system is associated with small- and medium-sized farms and, in many cases, this system is present alongside cropping systems (Ruiz 1990). Labour is supplied by the family members except for occasional hiring of labourers for non-routine tasks such as weeding, fence repair and pasture establishment (Ruiz 1990). The capital structure corresponds to the extensive character of the system but it is also indicative of its resilience to unfavourable economic situations (Seré and Rivas 1987).

Relative importance of the dual-purpose system

The definition given above does not imply that there are clear-cut boundaries between the beef, dual-purpose and dairy systems. In fact, extensive work in Central America led researchers to partition the dual-purpose system depending on whether the emphasis was on milk or beef production (Ruiz 1981a). The resilience of this system is given by its flexibility to shift production emphasis in response to changes in prices and market opportunities. Thus, the dual-purpose herd may sometimes approach management characteristics of the dairy systems, while in other cases milking is done just to supply the household with milk for daily consumption. Support of this changing scenario is found in the data presented in Table 2, where not only are the three systems compared, but also the standard deviation implies overlap between these systems.

Table 2. *Main indicators of biological productivity of three cattle production systems in Costa Rica (each system with 36 farms).*

Output	System	Mean	± sd
Net weight (kg/ha)	Beef	70	53
	Dual-purpose	133	128
	Dairy	124	109
Mean weight (kg/AU)[1]	Beef	74	45
	Dual-purpose	82	37
	Dairy	60	60
Total milk (kg/ha)	Beef	103	112
	Dual-purpose	461	472
	Dairy	5484	2927
Milk per adult cow in herd (kg)	Beef	220	142
	Dual-purpose	556	285
	Dairy	3492	858

1. Animal unit.
Source: Wadsworth (1995).

Despite the inferior level of milk obtained from the dual-purpose system (as opposed to that from the specialised dairying), the large number of farmers involved underscores its importance in Latin America (Ruiz 1990). An illustration of this assertion is given in Table 3.

Table 3. *A sample of Latin American countries comparing the incidence of dual-purpose (DP) cattle systems and specialised dairying systems.*

Region or country	Total lactating cows (× 10^3 heads)	DP cows[1] (× 10^3 heads)	(%)	Milk from DP cows (% of total)[1]
Brazil	23,600	N/A		80
Central America (Belize, Costa Rica, El Salvador, Honduras, Nicaragua, Panama)	1901	1482	78	54
Colombia[2]	3200	2525	79	55
Peru	526	356	68	30
Venezuela	1180	1062	90	60

1. Calculations made by author based on indirect information from Castillo (1992), and Diaz Junior (1989). When needed, it was assumed that dual-purpose cows produce 800 kg milk/lactation.

2. Based on statistical data by Aldana Vargas (1996).

Source: FAO (1997), except for the case of Colombia.

Production factors

Changes in land use

Cattle production systems in Latin America are based on grazing as the principal source of feed, and this is perhaps more obvious in the tropical environment. Expansion of grazing land has been at the expense of forests, although cropping has also been affected (Table 4).

Table 4. *Estimates of main causes of deforestation, (% of total deforestation).*

Region	Crops	Livestock	Forest exploitation
South America	25	44 (70 in Brazil)	10
Asia	50–60	Negligible (The Philippines and Indonesia to some extent)	20
Africa	70	Negligible	20

Source: Bruenig (1991) as cited by de Haan et al. (1998).

Since 1996, the inventory of livestock in Latin America (for example, total number of beef cattle or milking cows) has reached a plateau (FAO 1997). From 1979 to 1984, the area in permanent pastures increased by 11,895 million hectares. In the next 5-year period, this increase was repeated but in the 1989–94 period, expansion of pastures decreased to 3604 million hectares. In the last five years, informal reports indicated that there has not been any significant change in pasture area although deforestation continues. Between 1989 and 1994, 8402 million hectares of forests were lost, although this loss fell by 60% from the previous 5-year period.

Taking Central America as a focal point, 27% of the land is used to support cattle systems comprising 10 million heads (Table 5). Low stocking rate indicates that these systems are extensive in nature, although there are differences between and within countries. For example, the smallest country in the region, El Salvador, with only 21 thousand km^2, has an average stocking rate of 2 heads/ha, while Nicaragua, the largest Central American country, has a stocking rate of 0.3 heads/ha (the latter figure is abnormally low partly as a result of massive depletion of animal stocks due to a long internal warfare).

Table 5. *Some descriptors of the livestock sector in Central America.*

Total area (× 10^6 ha)	49.9
Grazing land (%)	27
Forest land (%)	39
Cattle population (× $10^{3)}$	10,171
Stocking rate (heads/ha pastures)	0.8

Source: Pérez (1999).

The Pacific slope of the Central American Isthmus is representative of the dry lowland ecozone, with a dry season lasting up to seven months. In contrast, the Atlantic slope is wet and there is almost no dry season.

In view of policies in the past that favoured the expansion of the agricultural frontier, increases in animal production were mostly due to increases in pastureland and stock. Therefore, there was little need to adopt improved technology to achieve higher production levels. As restrictions to horizontal growth in agriculture are being imposed, there is a growing sense that the only way to maintain production growth and, at the same time protect natural resources, is through intensifying land use, and animal production.

This challenge is further strengthened by the fact that large proportions of the land are already seriously eroded or degraded; for example, 45% in El Salvador and 17% in Costa Rica, according to Leonard (1987). It is reasonable to expect that even greater tracts of land have been lost due to the dramatic impact of hurricane Mitch in 1998. Renovating degraded pastures, using modern techniques and improved pastures, should not only reduce the pressure on existing forests but would permit producing required animal products by using only half of the land dedicated to livestock at the present time (Serrao 1991, as cited by Pezo et al. 1992).

Forage availability

It has been demonstrated that the tropics have a great advantage in terms of pasture production compared to the temperate zones. A number of factors will affect the rate at which biomass is produced. Some of these are grazing system, stocking rate, available humidity, pasture species, fertilisation level, type of soil etc. Data in Table 6 illustrate how much variation can be expected in herbage production when different pastures are compared.

Table 6. *Biomass yield of different pastures.*

Species	Kg DM/ha per day
Humid tropics	
Native grasses (*Axonopus, Paspalum*)	16.0–22.0
B. Ruziziensis + *P. phaseoloides*	24.7–53.7
Cynodon nlemfuensis	88.7–103.6
Temperate	
Perennial ryegrass	35.6

Sources: Mitchell (1960), Cubillos (1982).

Nutritive value of tropical pastures

Minson (1981), reviewing the differences between tropical and temperate pastures, set the stage for much of the research concerning improving tropical grasses and legumes. Many of the assertions given in this paper remain true to this day. Some of the deductive conclusions include:

- dry matter (DM) intake of tropical grasses is lower than of temperate grasses (56 vs. 71 g DM/day per metabolic weight).
- DM digestibility is also lower in tropical grasses (62 vs. 71%)
- the lower DM intake and digestibility in tropical grasses are due to a high fibre content (a median of 35 vs. 23% in temperate pastures)
- protein levels in tropical grasses are generally lower than in temperate grasses. Twenty-two percent of all observations for tropical grasses fell below 6% crude protein (CP) compared with only 6% of all observations with temperate species.

Since Minson's (1981) work was based on monthly regrowths (therefore, succulent material), it can be stated that these differences are even more contrasting when tropical grasses in the dry season are considered. Tropical grasses in the dry season may actually show values of less than 2% CP, such as the case of Jaragua grass (*Hyparrhenia rufa*), a result that cannot be prevented even with N fertilisation (Tergas et al. 1971).

The nutritive value of tropical pastures is not only dependent on the species, level of fertilisation and season but also affected by other factors. For example, Pezo et al. (1992), reviewing the literature and their own work, found that:

- protein solubility tended to be low in species that are high in tannins (such as legumes)
- amino-acid composition was rather constant regardless of species, age or soil fertility
- non-protein nitrogen varied between 0 and 25% of the total N, although in some forages and under certain conditions, nitrates might reach toxic levels (greater than 6%)
- mineral content was highly variable among species and depends on the levels present in the soil. In the particular case of P, nearly two-thirds of the tropical grasses show levels below 0.24%. Legumes tended to be richer in Ca and Mg than grasses
- attention should be paid to anti-nutritional factors because they may affect digestibility and feed efficiency. Some factors may cause poisoning and even death. Examples include hydrocyanic acid, tannins, alkaloids, mimosine and coumarins
- ambient temperature was a major factor affecting nutritive value. High temperatures not only increase the plant's rate of growth but also accelerate the ageing process resulting in

lignification of the cell wall and, consequently, in lower digestibility. Using trees for shade will reduce concentrating soluble carbohydrates in grasses but may increase the protein content, especially if the trees are legumes
droughts were detrimental to the nutritive value of forages causing decline in protein, digestibility and intake. However, occasional deficits of water in the soil may delay ageing in grasses.

Availability of other feed resources

Other feed resources can be used in feeding systems. Some are agro-industrial by-products and residues; others are products or by-products of cropping, harvesting and processing of crops at the farm level. These by-products and crop residues are heterogeneous in nutritional value and seasonal in availability. The strategy in their use as feeds will depend on whether the intention is to mitigate the effects of pasture scarcity in the dry season or to enhance productivity through pasture supplementation. A classification of the alternative feed resources is given in Table 7, while availability coefficients are presented in Table 8.

Table 7. *Some tropical crop residues and agro-industrial by-products of potential use in animal feeding.*

Feed resources	Nutritive value
Energy-rich feeds	Digestible energy (Mcal/kg DM)
Blackstrap molasses	3.47
Citrus pulp	3.01
Green banana rejects	3.0
Coffee pulp	2.61
Protein-rich feeds	Digestible protein (% of DM)
Cotton seed meal	36.2
Citrus seed cake	40.1
Copra (coconut cake)	18.6
Chicken litter	22.3
Blood meal	62.3
Wheat meal	17.8
Fibrous feeds	% DM as feed
Sugarcane bagasse	90.0
Sugarcane tops	23.0
Cornstalk, without grain	85.0
Rice straw	80.8
Pineapple bran	85.3
Wheat straw	80.0
Sweet potato leaves	18.0
Cacao pods husk	16.6
Banana leaves	20.5
Banana stalks	5.6

Source: Ruiz et al. (1984).

Table 8. *Coefficients for calculating availability of non-traditional feeds.*

Residue or by-product	Coefficient
Rice straw	1091 kg/ha[a]
Rice polishings	13% of whole grain
Soybean straw	Seed:straw ratio = 1.1:1
Empty soybean pods	Seed:pod ratio = 0.9:1
Soybean oilcake	79% of seed
Cornstalk, no grain	Straw:grain ratio = 1.92:1
Corncob	Grain:cob ratio = 4:1
Bean straw	906 kg/ha[a]
Wheat straw	Grain:straw ratio = 1:1
Cotton straw	Straw:cotton fibre ratio = 3:1
Cotton husks	Husk:seed cake ratio = 0.54:1
Cottonseed cake	47% of cotton fibre
Residue from cotton spinning mill	7% of cotton bales
Sugarcane tops	25% of whole plant[a]
Sugarcane bagasse	35% of cut stalk

a. Fresh (as feed) matter.
Source: Ruiz et al. (1984).

As is the case with tropical grasses and legumes, there are antinutritional factors present in some tropical agro-industrial by-products and crop residues. For example, hydrocyanic acid in cassava leaves and stems (although it can be easily destroyed); tannins in banana stalks, leaves and peelings, as well as in sorghum, which inhibit rumen micro-organism activity causing a depression in fibre and protein digestion. Gossypol is present in cottonseed cake and trypsin inhibitors in soybean seed meal (Devendra 1988).

Animal genetic resource

The modest nutritive value of tropical feed resources, the limited technical ability of the farmers and their low capital base favour production systems that are low or moderate in intensity based on animals of intermediate genetic potential (Vaccaro 1987). Through the years, farmers have developed the dual-purpose system which represent a means of reducing risks while retaining a high degree of flexibility (allowing them to emphasise milk or beef, according to market situations).

Dual-purpose herds are of undefined mixed breeding. There are great variations in the proportions of Creole, zebu and European breeds in dual-purpose herds but are mainly determined by the intensity of the system to produce more milk or beef. Little information is available on these dual-purpose breeds. In a review of 473 scientific papers published between 1974 and 1984, Vaccaro (1989) found that most of the studies (27%) was in the area of genetics. Most studies also focused on specialised systems (13% for beef and 12% for dairy) while only 2% were on dual-purpose system.

Taking into account published data from 1072 farms in Bolivia, Brazil, Colombia, Costa Rica, Honduras, Panama and Venezuela, plus information obtained from 234 herds in Brazil, Mexico, Panama and Venezuela, Vaccaro (1989) arrived at non-weighted averages that describe the main characteristics of the dual-purpose herds in Latin America (Table 9).

Table 9. *Some characteristics of commercial dual-purpose herds in the American tropics.*

Production parameter	Range	Preferred value[1]
Milk production (kg)		
Cow/day	2.8–6.5	4
Cow/lactation	749–1564	1180
Cow/year	186–1156	621
Lactation length (days)	244–311	290
Calving rate (%)	39–81	64
Age at first calving (months)	32–43	37
Weight gain (kg/day)		
Calves	0.29–0.48	0.37
Post-weaning		0.22
Productivity		
Stocking rate (AU/ha)	0.72–1.9	1.4
Production of:		
Milk (kg/ha per year)	182–749	476
Beef (kg/ha per year)	45–192	116
Pastures		
Native (% of total)	33–87	64
Farms applying fertiliser (%)	8–50	21
Supplementation		
Farms using (%):		
Commercial feeds	6–73	28
Some energy/protein supplement	10–73	41
Minerals (other than salt)	13–83	56
Breed groups (best estimate)		
Cows (% of total)		
European × zebu/Creole	33–83	65
Zebu/Creole	2–47	21
Bulls (% of total)		
European × zebu/Creole	10–48	35
Zebu/Creole	38–47	40
Management		
Bull:cow ratio	1:3–1:195	1:22
Farms that (%):		
Use records	2–33	15
Control endoparasites	47–100	70
Vaccinate against brucellosis	15–47	31

1. Non-weighted average of all average values published.

Source: Vaccaro (1989).

Table 9 not only describes the low production performance and deficient management of the dual-purpose system but also demonstrates that there are several aspects in which this system can be improved, as well as the potential for this improvement.

Introducing European breeds into the dual-purpose herds has produced mixed results (Teodoro and Lemos 1992), depending on the local conditions, suggesting a strong genotype × environment interaction. This is confirmed by experiments such as that conducted by Madalena et al. (1990) involving 66 farms in south-east Brazil (Table 10).

Table 10. *Milk production parameters of various crosses of Holstein × Guzera under two levels of management.*

	High level of management		Low level of management	
Genetic group Holstein/Guzera	Lactation length (day)	Milk production (kg)	Lactation length (day)	Milk production (kg)
First lactation				
1/4	211	1396	268	1180
1/2	305	2953	375	2636
5/8	191	1401	283	1423
3/4	329	2981	367	2251
7/8	295	2821	304	1672
>31/32	365	3147	258	1226
Second lactation				
1/4	185	1299	232	1247
1/2	252	2384	308	2370
5/8	218	1648	252	1333
3/4	283	2807	272	1873
7/8	318	2919	305	1879
>31/32	315	3147	278	1566

Source: Madalena et al. (1990).

From the data in Table 10, it is clear that crossbred cows respond less to an improvement in technology than the 3/4, 7/8 crosses and Holstein. However, the advantage shown by the Holstein was offset by an increase in calving intervals (Teodoro and Lemos 1992). It can also be observed that under a low level of management the half-bred had the longest lactation length and the highest level of milk production; these values declined as the percentage of Holstein blood increased.

Other parameters are also affected by introducing high proportions of European blood in milking cows in the tropics. For example, calf mortality (and even heifer mortality) increases have been observed when the proportion of European genes increase (Pérez 1979; Vaccaro 1979).

Pasture improvement

It is evident (from Table 6) that one of the most commonly used strategies to achieve higher productivity in the tropics is through the use of fast growing species. However, these have to be adapted to specific tropical conditions, particularly in the humid and the dry/humid tropics. Pezo et al. (1992) prepared a list of grass and legume species, which are promising in Latin America (Table 11).

Table 11. *Promising grasses and legumes for pasture improvement in the tropics.*

Species	Humid and sub-humid tropics	Dry/humid tropics
Grasses		
Andropogon gayanus		
Brachiaria brizantha		
B. decumbens		
B. dictyoneura		
B. humidicola		
B. ruziziensis		
Cenchrus ciliaris	–	
Chloris gayana	–	
Cynodon dactylon		
C. nlemfuensis		
Digitaria decumbens		
Panicum maximum		
Pennisetum purpureum		
Setaria sphacelata		
Tripsacum laxum		–
Legume trees		
Albizzia lebbeck	–	
Cajanus cajan	–	
Calliandra calothyrsus		–
Codariocalyx giroides	–	
Erythrina sp.		
Flemingia macrophyla		–
Gliricidia sepium		
Leucaena leucocephala	–	
Sesbania sesban		–
Herbaceous legumes		
Aeschynomene americana		–
Alysicarpus vaginalis		
Arachis pintoi		–

Cont'd.

Table 11. cont'd.

Species	Humid and sub-humid tropics	Dry/humid tropics
Centrosema acutifolia		
C. macrocarpum		
C. pubescens		
Clitoria ternatea	–	
Desmodium heterophylum		
D. ovalifolium		
Lablab purpureus		
Macroptilium atropurpureum	–	
Stylosanthes capitata		
S. hamata cv. Verano	–	
S. humilis	–	
S. guianensis		
S. macrocephala		
S. scabra	–	
Vigna unguiculata		

Source: Pezo et al. (1992), based on data from Mannetje (1991).

Recent research at CIAT is showing outstanding results with a shrub originating from the Amazon region of Brazil, Peru, Bolivia and Argentina. Particularly adapted to sub-humid tropical conditions, *Cratylia argentea* is being tested in Colombia, Costa Rica, Mexico, Guatemala, Brazil and Peru (Argel and Lascano 1998).

It is an accepted fact that milk production imposes a large nutritional demand. Native grasses alone cannot possibly meet this demand and, if grasses of higher quality are used, the expected milk output would be at best moderate, when crossbred cows (with European stock) are used. Higher levels of milk production can be achieved only if concentrates are used to supplement the diet; the amount of concentrates used will many times be prohibitive due to its high cost.

Using better grass species

When improved grasses are used, the farmer is faced with two options: Either fertiliser has to be applied on a regular basis, or grasses and legumes must be combined. In either case, there will be an increased supply of forage which then poses another question: Is the surplus to be ignored (allowing the animals to exert a higher degree of selectivity, therefore increasing the quality of the forage consumed), is the surplus to be conserved as hay or silage, or is the surplus to be avoided by increasing stocking rates? A review of the literature by Pezo et al. (1992) showed that in the case of cows grazing tropical pastures, with no supplementation, the expected maximum milk yield is in the order of 10 to 14 kg per day. This contrasts with the 20 to 25 kg of milk that can be obtained from temperate grasses

(Mannetje 1984, cited by Pezo et al. 1992). Data in Table 12 further illustrate the response of cows grazing fertilised tropical grasses.

Table 12. *Milk production from fertilised tropical grasses.*[1]

Pasture	Genotype	Stocking rate (cows/ha)	Milk (kg/cow per day)	Milk (kg/ha per year)
Digitaria decumbens	Crossbred	2.6	6.8	6014
D. decumbens	Crossbred	2.3	11	9125
D. decumbens	Crossbred	3	6.3	6840
B. mutica	Crossbred	3.6	11.6	15,257
Pennisetum purpureum			10	13,140
P. maximum	Crossbred	1.1	6.9	2667
P. clandestinum	Holstein	4.9	7.4	10,216
Various	Holstein	2.5	7.8–13.9	9950
Bracharia decumbens/Hyparrhenia rufa	Crossbred	3.2	8.6	10,430
Cynodon nlemfuensis	Holstein	5	–	17,244
C. nlemfuensis	Crossbred	5.9	6.5	13,604
C. nlemfuensis	Crossbred	6.7	8.3	11,798

1. Data from various authors, compiled by Pezo et al. (1992).

Barring genetic potential differences in animals, the reduced milk output associated with the use of tropical grasses appears to be the result of limitations in the intake of digestible nutrients (especially energy). The effect that energy shortage has on milk composition lends support to this contention (Stobbs and Thompson 1975).

Information given in Table 12 also illustrates the concept that different grass species elicit different responses in the animals that graze them. These differences are due to a number of factors such as capacity to respond to fertilisation, differences in the content of soluble carbohydrates, green biomass offered (i.e. capacity to support high stocking rates), rate of decline in nutritive value at the onset of the dry season, and palatability.

The high photosynthetic capacity of improved tropical grasses makes them highly responsive to fertilisation. The resulting increased biomass then allows an increase in the stocking rate and productivity per hectare. However, as Pezo et al. (1992) warned, increasing stocking rate reduces selectivity and, consequently, the quality of the ingested material and, ultimately, productivity per animal. Thus, this is an area where a decision must be made by the farmer, whether to seek optimum productivity per unit of land at the expense of production per cow. Table 13 is a collection of results from various authors who compared the effects of fertilisation and changes in stocking rate upon milk production of dairy cows.

Using legumes

As Pezo et al. (1992) argued, the exclusive grazing of legume pastures would be a waste of nutrients in view of the fact that the animals would be consuming more protein than they require, even in the case of lactating cows. Thus, there are two practical options for including legumes in a feeding system: a) as a protein bank, which can be used for short-term daily grazing or for cut-and-carry feeding, and b) as part of a mixed grass–legume pasture.

Table 13. *Milk production from fertilised tropical grasses at various stocking rates.*[1]

Pasture (rainfall, mm)	N application (kg/ha per year)	Stocking rate (AU/ha)	Milk (kg/cow per year)	Milk (kg/ha per year)
Pennisetum clandestinum (1050)	300	2.5	2467	6093
		3.3	2312	7606
		4.9	2068	10,216
P. clandestinum (747)	300	2.5	1964	4851
		3.3	1750	5757
		4.9	1753	8561
Panicum maximum cv. Gatton panic (1285)	200	2.5	2580	6650
		3.0	2450	7350
	400	2.5	2980	7450
		2.6	2850	8550
P. maximum cv. Gatton panic (1285)	300	2.6	3300	8580
Chloris gayana (800)	0	2.0	1123	2246
	300	2.0	2254	4508
Digitaria decumbens[1]	550	3.0	2303	6909
		4.5	2124	9558
		6.0	1928	11,568
Cynodon dactylon cv. Cross 1[2,3]	380	3.0	3519	10,560
		4.0	3005	12,012
		5.0	2978	14,875

1. Data from various authors, compiled by Pezo et al. (1992).
2. Cows were fed 0.5 kg concentrate per kg milk over 5 kg milk/cow per day.
3. Irrigation was used in the dry season at the rate of 50 mm every 18 days.

Protein banks

Using legumes (herbaceous, trees or shrubs) as protein banks has been evaluated with dairy cows and it is only recently being tested with dual-purpose cattle. With dairy cows, Suarez et al. (1987) found that cows grazing *D. decumbens* (fertilised with 235 kg N/ha per year) and with access to *L. leucephala* (30% of the total pasture area) produced 21% more milk than in the absence of the protein bank. However, milk production was 10% lower than that obtained through supplementation with commercial feeds. Similar results have been reported by Saucedo et al. (1980), who obtained a 17% increase in milk output in cows grazing *C. dactylon* with access to *L. leucephala*; and Paterson et al. (1981) who observed responses of 11 to 22% in cows grazing *H. rufa* and with limited access to banks of *Macrotyloma axillare* and *Glycine wightii*.

In the case of dual-purpose cows, the three experiments cited in Table 14 involve the use of protein banks as a supplemental cut forage. Despite the low milk production potential of these cows, it is clear from these experiments that there is an important role for legumes in improving dual-purpose systems.

Table 14. *Using protein banks in dual-purpose cows.*

Basal diet	Supplement	Saleable milk (kg/cow per day)	Increment (kg/cow per day)	
P. purpureum[1]	None	7.3	–	
	1 kg *L. leucocephala*	7.7	0.4	
	2 kg *L. leucocephala*	8.3	1.0	
P. purpureum[2]	None	5.1	–	
	1 kg *L. leucocephala*	5.4	0.3	
	2 kg *L. leucocephala*	5.5	0.4	
	2 kg *L. leucocephala* + 1 kg corn bran	6.5	1.4	
			I/C*	
H. rufa[3] +	3 kg chicken litter	3.48		–1.57
12 kg sugarcane +	1.5 kg chicken litter	3.35	–0.13	1.76
6 kg *C. argentea*	0 kg chicken litter	3.41	–0.07	2.14

* The ratio of income from the sale of milk over feeding costs.
Sources: 1. Muinga et al. (1992), 2. Muinga et al. (1995), 3. Holmann et al. (1998).

Cratylia argentea is becoming a promising pasture as a strategic source of protein and energy, particularly for the dry season, given that it is a shrub with deep root system, regrows quite readily and retains most of its leaves during the dry season. Animals do not like this forage when it is immature, a fact that adds attractiveness to its use during the dry season. It has crude protein of 20–25% and 50% digestibility. Recent data from Costa Rica indicates that *C. argentea* can substitute up to 30% of the commercial feed used in Jersey cows without any change in milk production. If *C. argentea* is increased to 70% of the total supplement, then milk decreases by 1.9 kg/cow per day (12.6 vs. 10.7 kg). However, the cost of producing 12.6 kg of milk (using commercial feed) is equivalent to the sale value of 10 kg of milk, while the cost of producing 10.7 kg of milk (using *C. argentea*) is equivalent to the value of 6 kg of milk. This means a greater profit margin (Argel 1999).

Insofar as legume trees are concerned, the Tropical Agricultural Research Centre (CATIE), in Turrialba, Costa Rica, and the Centre for Sustainable Agricultural Systems Research (CIPAV), in Cali, Colombia, have been working for a number of years in evaluating various tree species. However, no data on dual-purpose systems is available yet. Ibrahim et al. (1999) suggested that the best options at the present time are *Erythrina berteroana*, *E. poeppigiana*, *E. cocleata* and *Gliricidia sepium*. Data from the last four years on *E. berteroana* protein banks indicate that up to 6 MT of crude protein can be produced per hectare per year. This would be enough to supply 30% of the protein required by 46 adult cows that produce 8 kg milk/cow per day (Ibrahim et al. 1999).

Grass/legume associations

The grazing of legumes in association with grasses to prodcue milk has not received much emphasis by researchers. From results of trials carried out in tropical Latin America using dairy cows, Pezo et al. (1992) concluded that it is possible to obtain 9 to 13 kg of milk/cow per day as long as the proportion of legumes in the pasture is in the order of 20 to 30%.

It would be expected that the benefits from the use of legumes in association with grasses would be greater in the dry season, when dietary protein insufficiency is more evident. Recent studies, however, indicated that beneficial effects can be expected in both the dry and the rainy season.

In its annual report of 1990, CIAT (CIAT 1991) reported that milk production in Holstein cows can be increased by 16% in either the dry season or the rainy season when *B. dictyoneura* is associated with legumes (Table 15).

Table 15. *Response in milk production (kg/cow per day) to associations of* B. Dictyoneura *with legumes at the Quilichao Experiment Station, Cauca Valley, Colombia.*

	Dry season		Rainy season	
Pasture	Holstein	Crossbred	Holstein	Crossbred
B. dictyoneura alone	7.6	4.4	10.4	7.3
B. dictyoneura + *C. macrocarpum*	8.7	4.6	12.0	8.0
B. dictyoneura + *C. acutifolium*	8.9	4.6	12.2	8.3

Source: CIAT (1991).

A similar result was obtained in Turrialba, Costa Rica (humid tropics), where a 15% increase in milk production was due to the inclusion of *Arachis pintoi* in a *Cynodon nlemfuensis* pasture (van Heurck 1990). In this same trial, no positive response was observed when the associated legume was *D. ovalifolium*, which is unpalatable and of low digestibility.

Legume/grass associations have not been tested with dual-purpose cows until recently. It has been assumed that the benefits of legume/grass pastures can only be important in the case of high milk potential. The data in Table 15 indicate that Holstein cows responded with a 16% increase in production. The table also shows that the mixed breed cows had a modest increase of 4.5% in the dry season and in the rainy season, the increase in milk production was as high as 14%.

Pezo et al. (1992) referred to unpublished data from the humid tropics of Costa Rica concerning three farms where dual-purpose cows were used to measure the effect of *A. pintoi* associated with *B. brizantha* in comparison with *I. indicum* pastures (Table 16).

Table 16. *Effect of a legume/grass association on milk production (kg/cow per day) of dual-purpose cows.*[1]

Farm	Stocking rate (cows/ha)	*I. indicum* pasture	*B. brizantha* + *A. pintoi*
1	2.8	5.5	6.3
2	1.4	7.0	8.0
3	1.3	3.0	3.8

1. CATIE/CIAT data, reported by Pezo et al. (1992).

More recent data from Costa Rica strengthen the arguments in favour of the use of legume/grass associations in dual-purpose cattle systems. Observations at a farm located in San Jerónimo, involving 25 cows per group, during two years, showed that milk production can be increased by 3.7% when an improved grass species is used and when combined with *A. pintoi*, the magnitude of the increase is 6.8% (Table 17).

Table 17. *Milk production in dual-purpose cows during the rainy season, Costa Rica.*[1]

	Forage availability (kg DM/ha)		Milk production (kg/cow per day)	
Pasture	1997	1998	1997	1998
Native pastures	N/A	N/A	8.6[2]	7.5
B. brizantha	4113	4448	9.0	7.7
B. brizantha + *A. pintoi*	5105	5408	9.3	7.9

1. Argel (1999).

2. During 1997, cows were supplemented with 5 kg/day chicken litter and 1.5 kg soybean meal with a total cost of US$ 0.40/cow per day (not including transportation) while the incremental milk was worth US$ 0.13/cow per day. This practice was suspended in 1998.

The use of *Arachis pintoi* is spreading rapidly due to its aggressiveness, congeniality with many of the improved grasses commonly used in Central America and acceptability by the animal. However, its use is only feasible during the rainy season (unless irrigation is available), because at the onset of the dry season the plant quickly loses its leaf mass and stops growing (Argel 1999).

Supplementing with other feeds

Ideally, dual-purpose cows should derive all of their nutritional needs from tropical pastures alone. Since this is hard to accomplish in most cases (due to seasonal fluctuations in biomass availability, poor quality of native grasses, and many other factors), then the farmer is obliged to resort to supplementation as a strategy to maintain or increase production. Optimising this strategy depends on the skill applied in the management of the relative proportions of forage and supplement, the cost of the supplement, the market incentives for animal products, the critical moments when supplementation is required, the genetic capacity to respond to supplementation, the nutritional nature of the supplement and the administrative and technical ability of the farmer.

One of the more basic principles that escape the farmer and researcher mind is that supplementation has two major effects. At low levels, supplementation usually complements the pool of nutrients furnished by pasture and consequently the animal and economic performance improvement. This is called the *additive effect* of supplementation (Ruiz 1981b). If the supplement is given at levels over and beyond what is needed to complement the pasture, then there will be a *substitution effect* on consuming the basal feed. Since the supplement is usually of superior nutritive value than pastures, there is a further increase in animal output, up to a certain biological limit. At this stage, the decision on how much supplement to provide is strictly economic; that is, how much marginal return is expected from increasing levels of supplement.

Dairy cows in the tropics show an average increase of 0.3 kg milk for each kg of supplement (Combellas et al. 1979) which is three times less than in the case of high-producing cows in temperate zones. As stated for the case of research on legume/grass associations and protein banks, there is a lack of information on the effects of supplementation in dual-purpose cows. The effects are, in any case, extremely hard to assess in view of the fact that often the milk consumed by the calf is not taken into account; and when it is taken into account its measurement is done by rudimentary means (weighing before and after suckling), which introduces a large variation in the experimental results. It is thus reasonable to report milk production in dual-purpose cows as 'saleable milk', which is the milk actually hand drawn from the udder.

As has been pointed out before, energy is a major limiting factor for animal production based on pastures. Nevertheless, supplementation with protein-rich supplements or protein banks, has resulted in increases of 88 to 280 g in saleable milk (Sandoval Castro et al. 1997). The argument is that this type of supplementation ensures a higher flow of protein to the intestinal tract, which then stimulates mobilising fat reserves for the synthesis of milk (Ørskov and Dolberg 1985). Even then, experiments using by-pass protein have produced inconclusive results. A review by Combellas and Martínez (1982) showed responses between –50 g and 1 kg in milk yield, which hardly justify the cost involved in feeding protein-rich supplements.

Sandoval Castro et al. (1997), comparing responses to supplementation in various experiments, concluded that the best proportional response is obtained when low levels of supplementation are used. The question of what is low will depend on the nutritional condition of the cow, the status of the ruminal ecosystem, the stage of lactation, the genetic potential of the cow, and, of course, the nutritive nature and value of the supplement.

Given the situation just described, it is extremely difficult to suggest what levels and what types of supplements should be used in dual-purpose cows. Needless to say, in very critical times of the year any supplementation is welcome. In fact, under these conditions the supplement may become the basal diet.

Restricted suckling and milking frequency

Normally, dual-purpose cows are allowed to nurse their calves until they are weaned six to eight months later. The time spent together by the cow and the calf may start immediately after the morning milking until the next day when milk is collected again. Another common variation is to separate the cow from the calf at 4:00 pm local time to ensure more milk collection on the next day.

To make dual-purpose cattle system more attractive economically, attempts have been made in the past to copy artificial calf raising as practised in the specialised dairying system. However, the results have been disastrous: A large proportion of the cows dried up quickly, their lactation length reduced to 150 days, incidence of mastitis increased and difficulties in milking become common. Some of the cows that keep producing milk, despite permanent separating their calves reduced their milk production to such an extent that it was even insufficient to bucket-feed their calves. In addition, calf mortality increases (Alvarez and Saucedo 1982).

An option is to reduce the time dam and offspring spend together. Various schemes have been tried, from 30 minutes to 2–4 hours right after milking. When a restricted suckling time is practised, the milker must leave residual milk for the calf to harvest. The residual milk is always much higher in fat content than the rest of the milk. When there is no restriction in suckling time, the content of fat in saleable milk is 3.7% but when restricted suckling is practised the fat content in saleable milk goes down to 3.1% (Sandoval Castro et al. 1977). The higher fat content in residual milk will compensate the nutritional effect that reduced milk consumption may have on the calf development when restricted suckling is imposed.

Even though there are some contradictions on the effects of restricted suckling on milk production and reproductive performance, some responses are generally accepted as common in dual-purpose systems based on mixed breed cows (Sandoval Castro et al. 1997) and are presented in Table 18.

Table 18. *Performance of dual-purpose cows and calves when suckling is restricted.*[1]

Parameter	Effect
Effects on the cow	
Milk yield	More
Lactation length	More
Incidence of mastitis	Less
Calving–conception interval	More
Fat content in saleable milk	Less
Difficulties in milking	More
Weight loss	Less
Effects on the calf	
Weight gain	More
Health	More
Mortality	Less

1. Adapted from Alvarez Flores (1991) by Sandoval Castro et al. (1997).

Another management factor that must be considered in this paper is the number of times per day milking is practised in dual-purpose herds. Commonly, only one milking per day is done throughout Latin American dual-purpose herds. For example, in Costa Rica, 89% of all farmers with dual-purpose cows milk them once a day (Ruiz 1990) and all farmers brought the calf next to its mother in order to stimulate milk let down.

Increasing milking frequency in dual-purpose cows, has been shown to increase the amount of saleable milk (a fact that is also true in specialised dairying), under conditions of restricted suckling (Table 19).

Table 19. *Milking frequency and supplementation in dual-purpose cows with restricted calf suckling.*

	1 milking per day		2 milkings per day	
Parameter	Low suppl.	High suppl.	Low suppl.	High suppl.
Milk for sale (kg/day)	3.47	3.43	5.43	5.99
Milk consumed by calf (kg/day)	4.09	3.14	1.36	7.36
Total milk (kg/day)	6.62	7.53	1.36	6.79
Fat in saleable milk (%)	2.9	2.87	3.0	2.94
Protein in saleable milk (%)	2.93	3.04	2.75	2.91

Source: Sandoval Castro et al. (1997).

General conclusions and research needs

From the socio-economic view, it has been proven in this paper that the dual-purpose system is the most widely practised cattle system in tropical America. Moreover, it is associated with the small- and medium-size farms, which contribute most of the milk produced by tropical Latin American countries.

The investment in dual-purpose cows, installations, land and equipment is moderately small (compared to specialised dairy cows) so that profit-making requires only modest levels of milk production. Holmann (1990), for example, calculated that 50% Holstein cattle needed to produce 2000 kg of milk per lactation in order to obtain a net profit of US$ 100/cow per year (under lowland conditions), while pure Holstein cows placed in highland (cool) areas needed to produce 5000 kg milk.

As the concern for degradaing natural resources and environmental quality takes hold in the minds of producers, and as the new global economy imposes the need to become more efficient and competitive, many are accepting the idea that cattle systems must be intensified. Intensification will mean producing more on the basis of present resources already allocated, or to produce the same but with reduced amounts of resources, including land. Combining legumes, grasses and other feed resources may open new options to achieve this goal. For example, in the 1998 Tropileche Report (Holmann et al. 1998) it is projected that combining Brachiaria + Cratylia + sugarcane can free 27.5% of the land for other uses (including reforestation) when compared to a feeding system consisting of Cratylia and sugarcane. If *Arachis pintoi* is added (to be used in the rainy season) then the proportion of land available for other uses can go up to 36.5%.

Extreme intensification of the dual-purpose system may bring more problems than benefits. In this paper, reference has been made to the negative effects that artificial calf raising can have on the cow's performance. For this reason, it is felt that perhaps a 'medium' level of intensification may be the appropriate goal, at least for the time being, and given the present knowledge. What changes may be achieved by a moderate level of intensification can be foreseen from practical observations in south-east Mexico (Table 20) (Alvarez 1989).

As pointed out in this paper, the dual-purpose system is one where a number of interactions and mechanisms coexist with each other. Any effort to improve this system must necessarily be based on a more thorough understanding of these relationships and functions.

Table 20. *Comparison of the traditional dual-purpose cattle system and one where some improvements have been made.*

Parameters	Traditional	Semi-intensive	Improvement (%)	Changes
Milk production				
Kg/cow per day	3	5	67	a
Lactation length (days)	180	240	33	a
Milk/lactation (kg)	540	1200	122	a
Beef production				
Calf weight gain (kg/day)	0.4	0.6	50	b
Weight at 8 months age (kg)	126	174	38	b
Calf mortality (%)	10	6	40	b
Reproduction				
Calving interval (days)	500	430	14	c
Age at first calving (months)	36	30	17	d
Stocking rate (AU/ha)	1	1.5	50	e
Milk/ha per year (kg)	394	1626	313	
Beef/ha per year (kg)	92	222	141	

Changes:

a. Use of zebu × Brown Swiss or zebu × Holstein or other appropriate crossbreds
Improved pasture management
Strategic but moderate supplementation
Restricted suckling.
b. Restricted suckling
Preferential grazing
Supplementation based on molasses/urea and protein-rich by-products
Health control programme.
c. Better nutritional condition before and after calving, mineral supplementation, reduced suckling period, reproductive controls.
d. Moderate supplementation during critical periods.
e. Use of improved pastures, strategic fertilisation, supplementation during critical periods.
Source: Alvarez (1989).

Proper evaluation of milk yield in dual-purpose cows is hindered by the fact that the calf's intake of milk may be as high as 50% of the total milk synthesised, and this intake is highly variable and difficult to measure. One area of methodological research would be the design of procedures to measure the amount of milk suckled, other than weighing before and after suckling.

Work on animal genetics should continue. There is a gap in knowledge concerning the ability of European animals to adapt to hot climates. This problem and the need to increase milk production, have so far been mitigated through the use of crossbred animals. However, it would be important to put efforts in selecting animals that are better equipped for getting rid of excess body heat (Vaccaro 1982).

The work on improved grasses and legumes for tropical conditions is very promising, particularly now that researchers are seeking farmer participation. The bottleneck in adopting improved species is, for the specific case of legumes, a need for education and training. Farmers still perceive legumes as weeds; this is not a criticism of them but, rather, a calling of attention to put more emphasis on proper disseminating research results and on practically demonstrating its benefits and associated requirements. Another deterrent to widespread use of these species is the lack of or weak infrastructure for producing and marketing seeds. Many times a farmer is found to be eager to use a recommended pasture species but this attitude soon changes when he/she finds out that there is no seed available. This situation is changing now but more organised efforts are needed, including certifying such germplasm.

Most of the work conducted is usually lacking in economic and ecological evaluations. Researchers have tended to focus on observed effects. Applying a systems approach to research should help in widening the scientific horizon and putting the dual-purpose system in a proper context, possibly as a solid option through which to achieve a more balanced and ecologically responsible system of animal production.

Finally, introducing technology in dual-purpose system (as in any other agricultural system) should go hand in hand with appropriate policy measures that will help create better conditions for the farmers to market their products, or even the secondary products that he/she may choose to produce as well. There are inequalities in distributing the wealth generated by the livestock sector, and the solution of this problem is clearly a responsibility of policy makers. Access to credit is another aspect that requires a closer look. Often, small farmers are judged not to be credit worthy despite the fact that the farming systems they practice are usually more in tune with the objective of protecting the natural resource base and flexible enough to respond to market opportunities.

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Comparison of feed intake, digestibility of nutrients and performance of cattle (*B. indicus* and *B. indicus* × *B. taurus* crosses) and buffaloes (Swamp and Indian)

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Summary

The results of comparative studies of feed intake, digestibility of nutrients and performance of cattle and buffaloes in India are presented in this paper. From the information presented, it is rather difficult to draw distinct conclusions as almost all parameters show contradictory results. Therefore, it is necessary to conduct long-term studies with a sufficient number of male and female animals kept on the same diets, management and environment from birth to at least second lactation.

Introduction

Large volume of literature is available on feed intake, digestibility of nutrients and performance of *B. indicus*, *B. taurus*, *B. indicus* × *B. taurus* crossbred cattle and buffaloes showing the effect of diet, physiological status of the animals and climatic conditions but few comparative studies, however, have been conducted under similar conditions. The available comparative studies have been compiled here under the following headings: i) dry matter (DM) intake ii) digestibility coefficients and growth in performance of cattle and buffaloes.

DM intake in different breeds of *B. indicus* cattle and Murrah buffaloes

In nine out of ten studies presented in Table 1, the Hariana breed of *B. indicus* cattle and the Murrah breed of buffalo, either adult or growing after 6 month of age, were used. Breed of animals was not mentioned in the studies of Grant et al. (1974). Since there is a large difference in the body weight of cattle and buffaloes used in these studies, the values of DM intake have been worked out on the bases of per 100 kg body weight and per kg metabolic body weight ($W^{0.75}$) to enable meaningful comparison.

Table 1. *Comparison of DM intake in* B. indicus *cattle and buffaloes on different diets.*

Description of diets	Species	Live weight (kg)	DM intake Per day (kg)	DM intake Per 100 kg live weight	DM intake Per kg live weight
Wheat straw ± concentrate mixture[1]					
Summer season	Hariana	385	7.46	1.94	86
	Murrah	387	6.93	1.79	79
Autumn season	Hariana	386	7.22	1.87	83
	Murrah	388	6.48	1.67	74
Winter season	Hariana	387	6.34	1.64	73
	Murrah	391	6.57	1.68	75
Spring season	Hariana	388	5.56	1.43	63
	Murrah	400	6.53	1.63	74
Wheat straw in different form + concentrate mixture[2]					
Dry wheat bhoosa	Hariana	298	5.94	1.99	83
	Murrah	288	5.84	2.03	83
Water soaked wheat bhoosa	Hariana	315	6.87	2.18	91
	Murrah	312	6.61	2.12	89
Ground wheat straw	Hariana	287	5.99	2.09	86
	Murrah	294	6.03	2.05	84
Alkali treated wheat straw	Hariana	317	6.72	2.12	89
	Murrah	321	6.71	2.09	87
Without sodium sulphite	Hariana	250	5.3	2.11	84
	Murrah	248	5.33	2.16	85
With sodium sulphite	Hariana	274	5.64	2.06	83
	Murrah	260	5.89	2.26	90
Wheat straw + concentrate[3]					
Without linseed oil	Hariana	257	6.5	2.53	92
	Murrah	238	5.5	2.31	89
With 250 g linseed oil	Hariana	200	3.44	1.72	65
	Murrah	250	4.53	1.81	70
Sole feeding of Napier grass[4]					
Green cut at 45–60 days	*B. Indicus* Buffalo	–	–	2.2 1.8	–
Wilted (45 days)	*B. indicus*	–	–	2.3	–
	Buffalo			2.0	
Dried (60 days)	*B. indicus*	–	–	2.6	–
	Buffalo			2.1	
Sole feeding of oat hay or green forage[5]					
Oat hay	Hariana	134	3.07	2.29	78
	Murrah	201	3.56	1.77	67

Cont'd.

Table 1. cont'd.

Description of diets	Species	Live weight (kg)	DM intake Per day (kg)	 Per 100 kg live weight	 Per kg live weight
Oat green	Hariana	201	5.18	2.57	97
	Murrah	277	6.5	2.35	96
Maize green	Hariana	153	3.71	2.43	85
	Murrah	201	5.09	2.53	88
Cowpea green	Hariana	164	4.14	2.53	91
	Murrah	249	5.7	2.29	91
Berseem green	Hariana	219	5.86	2.68	103
	Murrah	301	7.26	2.41	100
Wheat straw ± concentrate ± green fodder 2 kg only[6]					
Age—6 months	Hariana	77	2.42	3.14	121
	Murrah	79	2.77	3.51	132
Age—12 months	Hariana	135	3.34	2.47	84
	Murrah	104	3.21	3.09	99
Age—18 months	Hariana	203	5.39	2.66	100
	Murrah	144	4.4	3.06	106
Wheat straw ± 2 kg concentrate ± 2 kg green dub grass[7]					
Sodium supplementation (100 g sodium bicarbonate)	Hariana	203	4.45	2.19	83
	Murrah	144	3.46	2.4	83
Partial sodium depletion	Hariana	203	1.79	0.88	33
	Murrah	144	1.84	1.27	44
Level of feeding[8]					
High level = wheat straw 5.04 kg, groundnut cake 500 g and crushed maize grain 460 g	Hariana	278	5.25	1.89	77
	Murrah	277	5.25	1.9	77
Medium level = wheat straw 3.18 kg, groundnut cake 200 g and crushed maize 1.62 kg	Hariana	288	4.42	1.54	63
	Murrah	286	4.42	1.54	63
Low level = wheat straw 2.26 kg, groundnut cake 100 g and crushed maize 1.64 kg	Hariana	290	3.55	1.23	51
	Murrah	286	3.55	1.24	51
Wheat straw + conc. 2 kg + green dub grass 2 kg[9]	Hariana	260	4.33	1.67	67
	Murrah	200	3.76	1.88	71
Green cowpea forage[10]	Hariana	270	5.36	1.98	80
	Murrah	246	5.36	2.18	86

Cont'd

Table 1. cont'd.

Description of diets	Species	Live weight (kg)	DM intake Per day (kg)	Per 100 kg live weight	Per kg live weight
Green maize forage	Hariana	266	5.16	1.94	78
	Murrah	270	5.33	1.97	80

Sources: 1. Raghavan et al. (1963), 2. Chaturevedi et al. (1973 a, b, c, 1974), 3. Varma et al. (1973), 4. Grant et al. (1974), 5. Jai Kishan (1974), 6. Raizada et al. (1973a), 7. Seth et al. (1973), 8. Balasubramanya and Raghwavan (1977), 9. Raizada et al. (1973b), 10. Upadhyay et al. (1973).

Mean DM intake per unit body weight has been found to be about 9–12% higher in Hariana cattle during summer and autumn seasons, almost the same during the winter season and about 15% less in spring season in comparison to DM intake in Murrah buffaloes (Raghavan et al. 1963). A marginal but non significant increase in DM intake due to physical or chemical treatments of wheat straw (grinding, water soaking and alkali treatment) has been observed in Hariana cattle in comparison to Murrah buffaloes (Chaturvedi et al. 1973 a, b, c) which showed a similar reverse trend when diet was supplemented with sodium sulphite as a source of sulphur (Chaturvedi et al. 1974). Supplementing straw based diets even with small quantity (250 g/head per day) of linseed oil resulted in about 30% decline in DM intake in Hariana cattle and about 21% decrease in Murrah buffaloes (Varma et al. 1973).

On a diet of green cereal and leguminous fodders, no significant differences have been observed in DM intake between Hariana cattle and Murrah buffaloes (Upadhyay et al. 1973; Jai Kishan 1974). However, a significant decrease in the intake of oat hay by Murrah buffaloes when compared to Hariana cattle was observed (Jai Kishan 1974). In the studies of Grant et al. (1974), DM intake from Napier grass fed either green, or dried, was always higher in *B. indicus* cattle than in buffaloes. Wilting and drying increased DM intake in both species.

In growing animals of both species, age had a significant effect on DM intake (Raizada et al. 1973a, 1973b). Highest DM intakes were observed in growing calves of about 6 months of age. Minimum DM intake was observed at about 2 years of age in both species. However, in this study, DM intake per unit body weight was higher for all age groups in Murrah buffaloes than in Hariana cattle. When the diet of these two groups of animals was supplemented with sodium, in the form of sodium bicarbonate (100 g/head per day in drinking water), there was no difference in DM intake. However, a sharp fall in DM intake was recorded on the withdrawal of sodium supplement and the reduction was much higher in Hariana cattle than in Murrah buffaloes (Seth et al. 1973).

Sixteen or 33% diet restriction had practically no effect on DM intake of Hariana cattle and Murrah buffaloes of similar body weight and age (Balasubramanya and Raghavan 1977).

DM intake in cattle and buffaloes

In most of the studies which are used here, comparison of DM intake was made either between Brahman cross (Brahman × Shorthorn) cattle and swamp buffaloes or between crossbred cattle (*B. indicus* × *B. taurus*) and Murrah buffaloes. In one of the studies pure

Shorthorn and Banteng (Bali cattle) were also used for comparison (Table 2). In most of the studies observations were made on adult animals.

Table 2. *Comparison of DM intake in crossbred cattle and buffaloes in feeding different diets.*

Description of diets	Species/breed	Live weight (kg)	DM intake (kg/day)	DM intake/100 kg live weight	DM intake/100 kg live weight
Hammer milled sorghum stuble of 5.2% CP[1]	Shorthorn	277	5.88	2.12	88.1
	Brahman cross	363	6.57	1.81	81.2
	Banteng	364	4.25	1.61	68.3
	Swamp buffalo	297	4.3	1.45	65.0
Same after 2 months of feeding	Shorthorn	269	4.77	1.77	71.6
	Brahman cross	343	5.39	1.57	67.6
	Banteng	248	4.12	1.66	66.1
	Swamp buffalo	265	4.33	1.63	66.1
Oat hay + groundnut cake (about 10% CP)[2]	Crossbred cattle	374	7.1	1.9	83.5
	Murrah buffalo	524	8.9	1.7	81.3
Oat hay + cluster bean meal (about 10% CP)	Crossbred cattle	390	7.8	2	88.9
	Murrah buffalo	505	9.1	1.8	85.4
Wheat straw + groundnut cake (about 8% CP)	Crossbred cattle	400	5.2	1.3	58.1
	Murrah buffalo	533	8	1.5	72.1
Wheat straw + cluster bean meal (about 8% CP)	Crossbred cattle	464	6.5	1.4	65
	Murrah buffalo	505	8.6	1.7	80.7
Lucerne hay[3]	Crossbred cattle heifer	221	5.68	2.57	99.2
	Murrah buffalo	320	6.01	1.88	79.5
Rice straw + concentrate[4]	Brahman × Shorthorn	383	7.22	1.89	83.4
	Swamp buffalo	405	9.32	2.3	103.2
Mixed forage	Brahman × Shorthorn	383	6.78	1.77	78.3
	Swamp buffalo	405	6.61	1.63	73.2
Rice straw + 50 g sun dried leucaena per kg DM of diet[5]	Brahman × Shorthorn	271	4.44	1.64	66.5
	Swamp buffalo	277	4.99	1.8	73.5
Rice straw + 206 g urea/day	Brahman × Shorthorn	545	7.03	1.289	62.3
	Swamp buffalo	466	6.43	1.38	64.1
Rice straw + mixture of sunflower meal and rice grain 492 g each + urea 154 g/day	Brahman × Shorthorn	543	8.09	1.49	71.9
	Swamp buffalo	472	7.6	1.61	75.1

Cont'd.

Table 2. cont'd.

Description of diets	Species/breed	Live weight (kg)	DM intake (kg/day)	DM intake/100 kg live weight	DM intake/100 kg live weight
Tropical grasses alone[6]	Brahman × Shorthorn	263	3.44	1.31	52.7
	Swamp buffalo	280	3.28	1.17	47.9
Tropical grass + urea	Brahman × Shorthorn	265	4.19	1.58	63.8
	Swamp buffalo	287	3.76	1.31	53.9
Tropical grasses alone	Brahman × Shorthorn	250	3.3	1.32	52.5
	Swamp buffalo	279	4.35	1.56	63.7
c + 4.6 g urea and 4.7 g urea	Brahman × Shorthorn	254	3.45	1.36	54.2
	Swamp buffalo	277	4.52	1.63	66.6
c + 20.3 g urea and 20.7 g urea	Brahman × Shorthorn	256	4.0	1.56	62.5
	Swamp buffalo	281	5.0	1.78	72.8
c + 100.7 g urea and 93.1 g urea	Brahman × Shorthorn	254	4.6	1.81	72.3
	Swamp buffalo	299	5.83	1.95	81.1
Wheat straw + concentrate mixture[7]	Crossbred cattle	383	6.55	1.71	75.6
	Murrah buffalo	467	8.5	1.82	84.6
Gram straw + concentrate mixture	Crossbred cattle	374	6.69	1.79	79.3
	Murrah buffalo	452	8	1.77	82.4
Wheat straw + cottonseed cake	Crossbred cattle	392	7.06	1.8	80.1
	Murrah buffalo	425	7.65	1.8	81.7
Wheat straw + mustard cake	Crossbred cattle	347	6.25	1.8	77.7
	Murrah buffalo	425	7.23	1.7	77.2
Gram straw + mustard cake	Crossbred cattle	342	6.5	1.9	81.7
	Murrah buffalo	425	7.65	1.8	81.7
Average of a + b + c	Crossbred cattle	–	6.6	1.8	79.8
	Murrah buffalo		7.51	1.8	80.2
Concentrate 1.1 kg to cattle and 1.15 kg to buffaloes + *ad libitum* wheat straw + Lucernehay (1:)[8]	Crossbred cattle	252	7.12	2.82	11.26
	Murrah buffalo	305	6.74		92.4

Cont'd.

Table 2. cont'd.

Description of diets	Species/breed	Live weight (kg)	DM intake (kg/day)	DM intake/100 kg live weight	DM intake/100 kg live weight
4% urea ammoniated paddy straw alone[9]	Crossbred cattle	200	5.04	2.52	94.8
	Murrah buffalo	231	5.2	2.25	87.8
Wheat straw + concentrate with alkali treated neem seed kernel cake[10]	Crossbred cattle	325	6.17	1.9	80.7
	Murrah buffalo	378	6.96	1.84	81.1

Sources: 1. Moran et al· (1979), 2. Sangwan et al. (1990), 3. Singh and Mudgal (1967), 4. Kennedy (1995), 5. Kennedy et al. (1992a), 6. Kennedy et al. (1922b), 7. Prasad and Pradhan (1990), 8. Bhatia et al. (1979), 9. Singhal et al. (1992), 10. Katiyar et al. (1992).

In *ad libitum* feeding of hammer milled sorghum stuble with about 5.2% crude protein, recorded DM intake was highest in the Shorthorn cattle, followed by Brahman cross, Banteng and swamp buffaloes. Prolonged feeding of this diet resulted in a significant fall in DM intake in same order after 2 months of feeding (Moran et al. 1979). The pattern of DM intake showed similar trends for a diet of forages or tropical grasses, being somewhat higher in Brahman cross than the swamp buffaloes. However, supplementing paddy straw with either *Leucaena* sp. leaf meal, urea, a mixture of sunflower meal and crushed rice grain, or a concentrate mixture, reversed the pattern of DM intake which was marginally higher in swamp buffaloes than the Brahman crossbred cattle. This trend of DM intake continued when tropical grasses were fed either alone or in supplementation with different quantities of urea, with the exception of one experiment (Kennedy et al. 1992 a, b; Kennedy 1995).

In feeding wheat straw or gram straw and concentrate mixture to supply the protein requirements, the DM intake was higher in Murrah buffaloes than the crossbred cattle (Prasad and Pradhan 1990). Sangwan et al. (1990) observed a similar trend on diets of wheat straw mixed with either groundnut cake or cluster bean meal for a CP level of about 8%. The trend of DM intake was reversed when wheat straw was replaced with oat hay due to which CP content rose to 10% in the mixed diets. Singhal et al. (1992) also reported higher DM intake in Murrah buffaloes than in crossbred cattle on *ad libitum* feeding of urea ammoniated paddy straw. Bhatia et al. (1979) reported similar observation on a ration of concentrate mixture, wheat straw and Lucerne hay. On the other hand, no difference has been observed between the two species on a diet of wheat straw or gram straw supplemented with mustard seed cake or cottonseed cake (Pradhan et al. 1997). Similar results were reported by Katiyar et al. (1993) on diets of wheat straw supplemented with concentrate mixture in which groundnut cake was partly replaced with alkali treated de-oiled neem seed kernel cake.

DM intake in dry and lactating *B. indicus* cows and Murrah buffaloes

In these studies, comparison was made between Murrah buffaloes cow with different dairy breeds of *B. indicus* cattle. Out of the four studies, three were carried out with dry animals and one on lactating animals (Table 3). In two trials mean DM intake was found to be lowest in Tharapakar cows, and significantly higher in Kangayam cows with further increases in Murrah buffaloes (Anyyaluswami et al. 1966). Contrary to this, Razdan et al. (1971) did not observe any such difference in DM intake per kg $W^{0.75}$ on diets of wheat straw supplemented with a concentrate mixture or with part of the protein replaced with 2 or 3% urea on nitrogen basis from the concentrate mixture. Sharma and Mudgal (1975) observed higher DM intake in Murrah buffaloes in comparison to Tharparkar cows on *ad libitum* wheat straw and 5 kg chaffed green sorghum forage supplemented with concentrate mixture without urea or 1, 2, or 3% urea on an iso-nitrogenous basis.

Table 3. *Comparison of DM intake in* B. indicus *cows and Murrah buffaloes on different diets.*

Description of diets	Species/breed	Live weight (kg)	DM intake (kg/day)	DM intake/100 kg live weight	DM intake/100 kg live weight
Dry cows					
Paddy straw + concentrates[1]					
First trial	Tharparkar	402	6.37	1.58	71
	Kangayam	289	6.45	2.23	87
	Murrah	380	9.55	2.51	111
Second trial	Tharparkar	414	6.5	1.57	71
	Kangayam	317	6.89	2.17	92
	Murrah	505	11.37	2.25	10
Wheat straw and concentrate mixture without urea[2]	*B. indicus*	386	5.38	1.4	62
	Murrah	580	7.27	1.25	62
Concentrate mixture with 2% urea	*B. indicus*	384	5.3	1.38	61
	Murrah	586	7.41	1.26	61
Concentrate mixture with 3% urea	*B. indicus*	380	5.33	1.4	62
	Murrah	574	7.36	1.28	62
Concentrate mixture without urea but about 25% less CP	*B. indicus*	373	5.09	1.37	60
	Murrah	573	7.37	1.29	63
Wheat straw + green sorghum 5 kg + concentrate mixture without urea[3]	Tharparkrar	362	4.45	1.23	54
	Murrah	433	6.03	1.39	63
Concentrate mixture with 1% urea	Tharparkrar	362	5.02	1.39	60
	Murrah	431	6.29	1.46	67
Concentrate mixture with 2% urea	Tharparkrar	356	4.85	1.36	59
	Murrah	440	6.08	1.38	63
Concentrate mixture with 3% urea	Tharparkrar	357	4.58	1.28	56
Lactating cows[4]	Tharparkrar	357	10.53	2.95	128
	Murrah	404	5.74	1.42	64
A diet of green maize + Lucerne hay and concentrate to meet requirements	Murrah	587	14.91	2.54	125

Sources: 1. Ayyaluswami et al. (1966), 2. Razdan et al. (1971), 3. Sharma and Mudgal (1975), 4. Sebastian et al. (1970).

The comparative DM intake showed no significant difference between lactating Sahiwal cows and Murrah buffaloes of comparable daily milk yields (7.2 kg in Sahiwal cows vs. 7.9 kg in Murrah buffaloes), when DM intake per unit metabolic body weight was compared. Dry matter intake per 100 kg body weight, however, was higher in Sahiwal cows. This was due to large difference in the body weight (Sahiwal 357 kg vs. Murrah 587 kg) of the two species (Sebastian et al. 1970).

Digestibility coefficient of DM and other nutrients

The information available on the digestibility of feeds and nutrients has been organised in a manner to facilitate more useful comparison. All studies using proximate analysis have been put together, and those using the detergent system of fibre analysis have been put together. Results for dry and lactating cows and buffaloes are presented separately.

Digestibility, crude protein (CP), ether extract (EE), crude fibre (CF) and nitrogen free extract (NFE) between *B. indicus* cattle and buffaloes

In most of the studies, DM digestibility in Murrah buffaloes was found to be higher than in Hariana cattle. Upadhyay et al. (1973) reported higher digestibility of DM, EE and NFE of cowpea and DM, CP, CF and NFE of green maize in buffaloes than in cattle, when compared with the values for these forages reported by Jai Kishan (1974) in the same species. He also reported similar DM digestibility for green maize, green oats and oat hay in the two species but it was somewhat higher in buffaloes for the leguminous forages.

Chaffing, grinding and soaking of wheat straw in water, had little effect on DM digestibility in the two species. Alkali treatment of wheat straw and supplementing the diet with sodium sulphite, however, caused higher DM digestibility in buffaloes than in cattle. The digestibility of other nutrients did not present a definite trend showing the effect of species of the animals (Chaturvedi et al. 1973a, b, c, 1974). Supplementation with 250 g linseed oil per head per day on a wheat straw and concentrate diet, resulted in a significant depression of the digestibility of DM, CP, CF, and NFE in buffaloes, but not in cattle (Varma et al. 1974). No explanation could be found for this observation. Higher digestibility of EE was reported in buffaloes in comparison to *B. indicus* cattle in a few studies (Jang and Majumdar 1962; Barsaul and Talapatra 1970; Pathak et al. 1973; Upadhyay et al. 1973; Jai Kishan 1974) (Table 4).

Digestibility, CP, EE, CF and NFE in *B. indicus* × *B. taurus* crossbred cattle and Murrah buffaloes

Mean values of the digestibility coefficients of DM, CP, CF and NFE in crossbred cattle and Murrah buffaloes are presented in Table 5. DM digestibility was found to be higher in buffaloes than in crossbred cattle by Bhatia et al. (1979) but almost similar in the two species by Sangwan et al. (1987). However, digestibility of CF in both the studies was higher in buffaloes than in cattle.

Table 4. *Comparison of digestibility coefficients of DM, CP, EE, CF and NFE in* B. indicus *cattle and Murrah or swamp buffaloes.*

		Digestibility coefficient				
Description of diets	Species	DM	CP	EE	CF	NFE
Sole feeding of fodders[1]						
Green cowpea (flowering)	Harriana	57.4	74.4	68.1	72.2	49.7
	Murrah	60.1	76.2	71.0	70.1	55.4
Green maize (milk stage)	Harriana	51.5	64.3	59.1	64.4	42.1
	Murrah	60.0	58	64.8	74.3	53.7
Green maize[2]	Harriana	60.7	65.6	63.6	65.5	65.6
	Murrah	60.9	63.6	68.3	70.2	62.5
Oat hay	Harriana	54.8	31.9	57.6	57.2	64.7
	Murrah	54.2	30.3	55.0	61.8	63.0
Green oats	Harriana	66.4	66.2	55.0	65.0	74.5
	Murrah	66.5	66.2	58.3	67.6	72.5
Green cowpea	Harriana	58.2	68.1	64.5	64.8	64.6
	Murrah	59.9	71.3	65.5	65.2	65.3
Green berseem	Harriana	67.1	72.1	52.0	67.8	75.5
	Murrah	69.8	75.3	57.0	68.4	78.0
Rice straw alone[3]	Ongole	37.6	24.4	–42.8	55.4	–
	Swamp buffalo	36.6	20.5	–37.6	53.1	–
Alkali treated rice straw	Ongole	46.9	20.4	12.3	69.8	–
	Swamp buffalo	49.7	25.2	27.4	71.1	–
Rice straw (70%) and leucaena meal (30%)	Ongole	42.1	46.5	43.9	51.9	–
	Swamp buffalo	38.6	43.3	30.2	46.5	–
Alkali treated rice straw (70) and leucaena meal (30)	Ongole	47.8	46.2	30.2	57.9	–
	Swamp buffalo	50.9	50.4	39.3	56.0	–
Chaffed and dried elephant grass	Ongole	52.7	64.3	58.5	53.9	–
	Swamp buffalo	52.7	61.8	54.5	55.7	–
Wheat straw, green forage and concentrate mixture[4]	Harriana	59.1	58.4	40.9	65.5	61.1
	Murrah	62.5	57.4	57.5	67.7	64.9
Same diet in adults	Harriana	59.4	59.1	45.5	63.7	60.9
	Murrah	64.2	61	51.9	71.1	64.4
Spear grass (post-flowering) and groundnut cake[5]	Harriana	53.5	49.5	62.9	61.6	52.9
	Murrah	54.1	47.5	74.1	62.0	53.2
Wheat straw and concentrate[6]						
Crushed wheat straw (Bhoosa)	Harriana	52.9	60.7		64.4	52.8
	Murrah	52.9	53.8		64.8	53.9

Cont'd.

Table 4. cont'd.

		Digestibility coefficient				
Description of diets	Species	DM	CP	EE	CF	NFE
Ground wheat straw	Harriana	54.1	59.4		62.9	53.1
	Murrah	51.9	53.9		58.7	53.1
Water soaked wheat straw	Harriana	52.3	50.6		57.7	58.3
	Murrah	54.8	50.5		55.8	60.6
Alkali treated wheat straw	Harriana	56.4	50.2		63.7	–
	Murrah	60.2	55.8		67.7	–
Without sodium sulphite	Harriana	56.0	67.8		50.0	58.8
	Murrah	60.4	64.7		55.3	61.0
With sodium sulphite	Harriana	53.0	68.4		50.0	56.2
	Murrah	57.6	64.7		55.3	61.0
Same without oil[7]	Harriana	55.1	60.7		64.3	56.4
	Murrah	59.6	55.7		66.1	62.0
With 230 g linseed oil	Harriana	54.7	64.0		40.2	7.7
	Murrah	58.6	47.7		57.3	54.9
Wheat straw 2.4 kg, urea-molasses liquid feed (2% urea) 4.8 kg and fish meal 200 g[8]	Harriana	48.7	49.3		41.9	70.2
	Murrah	60.0	46.3		44.3	72.0

Sources: 1. Upadhyay et al. (1973), 2. Jai Kishan (1974), 3. Moran et al. (1983), 4. Barsaul and Talapatra (1970), 5. Jang and Majumdar (1962), 6. Chaturvedi et al. (1973a, b, c, 1974), 7. Varma et al. (1974), 8. Pathak et al. (1973).

Table 5. *Comparison of digestibility coefficients of DM, CP, EE, CF and NFE in crossbred* (B. indicus × B. taurus) *cattle and buffaloes.*

Description of diets	Species	DM	CP	EE	CF	NFE
Wheat straw and luecerne hay (1:1) and concentrate mixture[1]						
1.1 kg	Crossbred cattle	55.9	56.3	48.7	48.7	67.6
1.15 kg	Murrah	62.0	55.1	49.9	56.3	70.3
Wheat straw (65%) and groundnut cake (35%)[2]	Crossbred cattle	50.1	61.5	73.6	51.9	50.6
	Murrah	49.4	71.3	74.5	59.3	49.7
Wheat straw (67%) and cluster bean meal (33%)	Crossbred cattle	54.7	72.4	73.4	52.8	54.7
	Murrah	54.5	70.9	71.3	56.8	54.3
Oat hay (68%) and groundnut cake (32%)	Crossbred cattle	59.3	62.7	76.5	57.6	58.9
	Murrah	60.1	74.8	72.7	64.6	60.3
Oat hay (77%) and cluster bean meal (83%)	Crossbred cattle	64.3	70.3	78.0	65.3	63.1
	Murrah	66.4	76.4	76.1	71.0	66.5

Sources: 1. Bhatia et al. (1979), 2. Sangwan et al. (1987).

Digestibility of DM, CP and various fibre fractions

Average digestibility coefficients of DM, CP and various fibre fractions in crossbred cattle and buffaloes have been summarised in Table 6a. Dry matter, cell wall content (CWC) and NDF digestibilities in cattle and swamp buffaloes are presented in Table 6b.

Table 6a. *Comparison of digestibility coefficients of DM, CP and detergent fibre fractions in cattle and buffaloes.*

Description of diets	Species	DM	CP	NDF	ADF	Cellulose	Hemi-cellulose	Lignin
Sole Napier grass[1]								
Green forage (45–60 days)	Cattle	54.1	61.3	50.3	–	60.6	60.5	26.2
	Buffalo	56.2	64.4	52.3	–	62.6	63.2	27.3
Wilted (45 day)	Cattle	59.1	65.0	55.7	–	66.1	65.8	32.6
	Buffalo	63.3	69.6	59.3	–	68.6	69.9	36.0
Dried (60 day)	Cattle	57.3	59.5	55.8		64.3	67.3	34.9
	Buffalo	57.2	62.7	54.8	–	64.2	69	–31.8
Ammoniated rice straw[2]	Crossbred cattle	56.0	14.3	9.0	51.9	–	91.1	–
	Murrah	54.5	13.9	56.8	50.5	–	88.1	–
Whet straw and concentrate	Crossbred cattle	55.3	39.9	56.4	43.4	54.2	73.4	–
	Murrah	57.0	37.8	57.4	46.0	56.2	73.9	–
Gram straw and concentrate	Crossbred cattle	55.0	53.3	4.7	37.7	38.0	75.0	–
	Murrah	59.3	52.7	53.3	39.7	36.7	74.7	–
Wheat straw and cluster bean meal[3]	Crossbred cattle	55.3	52.3	51.7	45.9	54.6	62.7	36.5
	Murrah	51.3	48.3	52.3	44.0	52.3	72.5	31.9
Wheat straw and groundnut cake	Crossbred cattle	49.8	54.2	47.3	39.5	51.6	66.5	19.6
	Murrah	52.4	51.3	51.8	44.2	55.3	70.4	28.8
Oat hay and cluster bean meal	Crossbred cattle	60.6	40.7	57.0	44.9	52.5	72.3	30.4
	Murrah	57.9	45.0	53.6	44.8	52.2	70.3	19.6
Oat hay and groundnut cake	Crossbred cattle	60.7	50.1	54.7	46.6	50.1	70.3	22.9
	Murrah	59.3	47.0	56.1	47.7	54.6	71.3	20.5
Wheat straw and cottonseed cake[4]	Crossbred cattle	42.9	57.5	40.2	31.4	45.3	58.1	–
	Murrah	54.1	61.1	49.5	37.8	55.7	73.7	–
Wheat straw and mustard cake	Crossbred cattle	49.4	65.8	40.2	38.2	51.6	40.4	–
	Murrah	49.9	63.5	39.4	35.9	48.7	45.9	–
Gram straw and mustard cake	Crossbred cattle	39.6	34.7	26.6	29.5	47.6	34.7	–
Exchange of rumen content	Murrah	43.2	49.4	29.7	36.7	51.9	33.6	–
Pre-exchange	Crossbred cattle	49.9	63.3	46.2	35.2	46.1	65.9	–
	Murrah	47.9	61.7	42.8	34.8	50.8	57.6	–

Cont'd.

Table 6a. cont'd.

Description of diets	Species	DM	CP	NDF	ADF	Cellulose	Hemi-cellulose	Lignin
After exchange	Crossbred cattle	51.1	61.7	46.1	38.4	50.7	62.6	–
	Murrah	48.2	59.3	41.5	35.7	52.7	51.1	–
After re-exchange	Crossbred cattle	51.6	56.5	49.5	42	54.1	64.3	–
	Murrah	50.2	53.2	46.5	42.6	54.9	53.9	–

Sources: 1. Grant et al. (1974), 2. Singhal et al. (1992), 3. Sangwan et al. (1990), 4. Bhatia et al. (1988).

Table 6b. *Comparison of digestibility coefficients of DM, cell wall content (CWC) and NDF between crossbred cattle and swamp buffaloes*

Description of diets	Species	Urea (g/day)	Digestibility (%)		
			DM	CWC	NDF
Tropical grasses[1]	Crossbred cattle	0.0	39.0	49.7	53.9
	Swamp buffalo	0.0	33.7	39.1	44.8
	Crossbred cattle	4.7	40.6	51.5	57.1
	Swamp buffalo	4.7	35.2	41.7	45.3
	Crossbred cattle	20.3	41.5	49.9	56.0
	Swamp buffalo	20.8	36.0	41.5	46.7
	Crossbred cattle	100.7	41.8	48.5	57.1
	Swamp buffalo	93.1	39.8	44.5	51.4
Rice straw with energy and protein[2]	Crossbred cattle	–	54.0	52.0	–
	Swamp buffalo	–	47.0	51.0	–

Sources: 1. Kennedy et al. (1992), 2. Kennedy (1995).

Digestibility coefficients of DM, CP and various fibre fractions of green Napier grass and wilted young Napier grass were higher in buffaloes than in cattle but similar for the two species on a diet of dried Napier grass of 60 days growth (Grant et al. 1974). Prasad and Pradhan (1990), and Bhatia et al. (1998) reported higher digestibility in Murrah buffalo than the crossbred cattle . Contrary to this, marginally higher digestibility of DM and fibre fractions of ammoniated rice straw were reported in crossbred cattle than the Murrah buffaloes (Singhal et al. 1992). However, in the studies of Sangwan et al. (1990) variable patterns were observed. Exchange of rumen contents between crossbred cattle and Murrah buffaloes resulted in the increased DM and cellulose digestibility in both the species which showed further improvement on re-exchanging the rumen contents in the same set of animals (Singh et al. 1997).

In a series of studies on the feeding of tropical grasses with different levels of urea and rice straw supplemented with energy and protein feeds, the digestibility of DM, CWC and NDF were always higher in crossbred cattle than in swamp buffaloes (Kennedy et al. 1992; Kennedy 1995).

Digestibility of DM, CP, CF and NFE in dairy breeds of *B. indicus* cows and Murrah buffaloes

In an early study Ayyaluswami et al. (1966) reported higher DM digestibility in buffaloes than the two breeds of *B. indicus* cows (Table 7) Razdan et al. (1971) made similar observations . However, on similar diets with small quantity of green sorghum forage, Sharma and Mudgal (1975) observed little or no difference between the two species.

Table 7. *Comparison of digestibility coefficients of DM and proximate principles in dry or lactating* B. indicus *cows and Murrah buffaloes.*

Description of diets	Species	DM	CP	EE	CF	NFE
Rice straw and concentrate[1]						
First trial	Tharparkar	56.2	–	–	–	–
	Kangayam	51.3	–	–	–	–
	Buffalo	58.1	–	–	–	–
Second trial	Tharparkar	56.9	–	–	–	–
	Kangayam	54.8	–	–	–	–
	Buffalo	58.3	–	–	–	–
Wheat straw and						
concentrate without urea[2]	*B. indicus*	49.0	53.5	68.8	65.7	46.6
	Murrah	52.4	53.9	70.5	69.3	50.2
Concentrate with 2% urea	*B. indicus*	47.3	42.4	60.2	67.8	42.1
	Murrah	52.8	50.3	68.6	72.5	53.0
Concentrate with 3% urea	*B. indicus*	49.6	49.6	61.1	66.1	43.7
	Murrah	52.8	53.8	63.4	69.3	49.6
Concentrate without urea but CP 16.5% against 21–23% in a, b, and c	*B. indicus*	46.8	27.0	57.4	58.7	48.8
	Murrah	54.3	40.8	60.4	64.6	57.4
Wheat straw and 5 kg green sorghum concentrate without urea[3]						
	Tharparkar	48.1	55.0	62.1	59.1	45.4
	Murrah	49.9	59.1	66.7	66.9	43.8
Concentrate with 1% urea	Tharparkar	48.9	54.1	62.6	60.0	47.1
	Murrah	50.5	55.0	68.8	63.7	47.7
Concentrate with 2% urea	Tharparkar	51.5	47.6	65.1	58.7	54.4
	Murrah	53.2	51.5	64.6	63.2	53.5
Concentrate with 3% urea	Tharparkar	48.6	48.2	67.6	54.7	52.3
	Murrah	48.8	50.0	69.2	58.6	49.3
Lactating animals eating green maize, lucerne hay and concentrate mixture[4]	Sahiwal	67.1	70.0	60.8	64.7	62.2
	Murrah	69.6	69.2	65.7	79.8	63.0

Sources: 1. Ayyaluswami et al. (1996), 2. Razdan et al. (1971), 3. Sharma and Mudgal (1975), 4. Sebastian et al. (1970).

The digestibility of DM, EE and CF was higher in lactating Murrah buffaloes, as compared to lactating Sahiwal cows yielding comparable quantity of milk daily but the differences were generally marginal except the very high digestibility of CF in buffaloes than the cows (Sebastian et al. 1970).

In vitro digestion of DM, OM and cellulose (cellu) of some feeds/diets in cattle (*B. indicus* or *B. indicus* × *B. taurus* crosses and buffaloes

From the mean values for *in vitro* digestion of DM, OM and cellulose of some feeds and diets in cattle and buffaloes presented in Table 8, it will be clear that there is a great variation due to species in different studies. Gupta et al. (1970) observed practically no difference in DM digestibility and Ludri et al. (1971) observed no difference in DM and cellulose digestibility. On the other hand, Gupta et al. (1970) and Ichhponani et al. (1971) observed considerably higher digestibility of cellulose of feeds incubated with the rumen liquor of buffalo in comparison with the rumen liquor of *B. indicus* cattle. Bhatia et al. (1998) observed variable results and it is rather difficult to find out the effect of species on DM, OM and cellulose *in vitro* digestibility. There is, hence, a need for further comparative studies on the two species maintained under same feeding management. While selecting experimental animals, care should be taken to select animals of same age, sex, body weight and physical condition. There is also a need to conduct *in vitro, in sacco* and *in vivo* (by feeding and digestion trial) studies simultaneously with different kinds of feeds and diets to obtain conclusive results on the effect of species on the digestibility of feed and nutrients.

In sacco ruminal disappearance of DM, neutral detergent fibre (NDF) and acid detergent fibre (ADF) of different diets in cattle and buffaloes

The average values of *in sacco* ruminal disappearance of DM, NDF and ADF of various diets determined at 12, 24, 48 and 72 hours incubation in the rumen of cattle and buffalo in nylon bags are presented in Table 9. For most of the diets *in sacco* ruminal disappearance of DM, NDF and ADF was higher in buffaloes than in cattle (Bhatia et al. 1998). No logical explanation could be given for the difference, except the interaction between the physiochemical composition of the diets and microbial composition in the rumen of the two species. Probably more precise studies are necessary to obtain a conclusive result on the effect of species on the digestibility of fibre fractions of diets.

Table 8. *Comparison of in vitro digestion of DM, OM and cellulose in cattle and buffalo.*

Description of diets	Species	DM	OM	Cellulose
Urea (1%), molasses (10%) impregnated rice straw[1]	Hariana	49.0	46.5	56.8
	Murrah	49.8	45.1	59.9
Wheat straw:green berseem (1:1 on DM basis)[2]	Hariana	–	–	24.0
	Murrah	–	–	32.4
Wheat straw and concentrate mixture	*B. indicus*	–	–	24.4
	Buffalo	–	–	26.6
Wheat straw and green bajra cowpea mixture	*B. indicus*	–	–	26.4
	Buffalo	–	–	30.1
Wheat straw[3]	*B. indicus*	45.1	–	42.2
	Buffalo	45.4	–	42.0
Wheat straw supplemented with:				
Berseem hay	Cattle	39.4	40.0	–
	Buffalo	44.0	43.9	–
Lucerne hay	Cattle	49.8	49.1	–
	Buffalo	46.2	46.3	–
Groundnut cake	Cattle	51.3	54.2	–
	Buffalo	50.2	51.3	–
Mustard cake	Cattle	55.7	55.2	–
	Buffalo	56.0	55.9	–
Cottonseed cake	Cattle	51.8	55.4	–
	Buffalo	57.2	56.6	–
Sunflower seed cake	Cattle	40.8	47.1	–
	Buffalo	37.4	44.0	–
Sesame cake	Cattle	34.6	41.3	–
	Buffalo	44.9	52.4	–
Concentrate mixture	Cattle	55.2	57.7	–
	Buffalo	55.2	57.7	–
Paddy (rice) straw and groundnut cake	Cattle	49.0	48.9	–
	Buffalo	47.6	46.5	–
Mustard cake	Cattle	58.5	66.0	–
	Buffalo	51.4	58.9	–
Cottonseed cake	Cattle	43.8	49.5	–
	Buffalo	56.8	52.8	–
Concentrate mixture	Cattle	65.2	64.6	–
	Buffalo	63.9	63.4	–

Sources: 1. Gupta et al. (1970), 2. Ichhponani et al. (1971), 3. Ludri et al. (1971).

Table 9. In sacco *ruminal disappearance of DM, NDF and ADF in cattle and buffaloes.*

Description of diets	Species	DM	NDF	ADF
Wheat straw and Berseem hay	Cattle	48.3	33.2	49.1
	Buffalo	46.7	30.4	446.7
Lucerne hay	Cattle	44.7	24.5	31.7
	Buffalo	44.9	27.2	31.8
Groundnut cake	Cattle	47.1	24.3	33.2
	Buffalo	52.4	32.7	41.8
Mustard cake	Cattle	50.3	25.9	26.9
	Buffalo	56.3	33.5	35.2
Cottonseed cake	Cattle	42.5	16.1	16.3
	Buffalo	49.3	28.6	36.5
Sunflower seed cake	Cattle	42.0	26.5	30.9
	Buffalo	43.2	29.8	33.4
Sesame cake	Cattle	41.8	20.3	24.9
	Buffalo	44.1	21.0	26.8
Concentrate mixture	Cattle	53.5	15.3	17.5
	Buffalo	64.1	24.5	28.9
Paddy (rice) straw and Groundnut cake	Cattle	47.3	25.1	30.5
	Buffalo	49.4	24.9	31.0
Mustard cake	Cattle	44.3	24.7	29.7
	Buffalo	46.2	29.9	32.6
Cottonseed cake	Cattle	43.3	24.8	23.6
	Buffalo	46.4	28.3	26.0
Concentrate mixture	Cattle	54.8	35.2	30.6
	Buffalo	56.3	35.8	32.3

Source: Bhatia et al. (1998).

Rumen fermentation metabolites in cattle and buffaloes

Comparison of volatile fatty acid (VFA) content in strained rumen liquor (SRL)

The information available on VFA content in SRL of cattle and buffaloes on the feeding of same diets under similar managements are presented in Table 10, along with the percentage of acetic, propionic and butyric acid (including other minor acids). In most of the studies little or no difference was observed in VFA content between the two species when fed different diets (Kahlon et al. 1970; Chaturvedi et al. 1973 a, b, c, d; Pathak et al. 1973). However, Varma et al. (1973) observed higher VFA content in the SRL of Murrah buffaloes than in Hariana cattle when supplemented with linseed oil. Similar differences have been reported on a diet of green cowpea (Upadhyay et al. 1973), oat hay (Jai Kishan 1974) and rice straw with molasses (Abdullah et al. 1992). Contrary to these studies, considerably lower VFA contents were observed in SRL in Swamp buffaloes in comparison to *B. indicus* or *B. indicus* × *B. taurus* crosses, on similar diets in different studies (Moran et al. 1979; 1983, Kennedy et al. 1992a, b; Kennedy 1995).

Table 10. *Comparison of VFA content in the strained rumen liquor (SRL) of cattle and buffaloes on the feeding of same diet.*

Description of diets	Species	VFA (mmol/l)	Percent composition		
			Acetic	Propionic	Butyric
Crushed maize and groundnut cake (1:1) 800 g, green berseem 5 kg and *ad libitum* wheat straw[1]					
Faunated or normal	*B. indicus*	72.1			
	Murrah	72.3			
Partial defaunation	*B. indicus*	60.4			
	Murrah	68.9			
Concentrate mixture of equal parts of crushed barley, groundnut cake and wheat bran with minerals and wheat bhossa2	*B. indicus*	74.5	73.2	16.6	10.2
	Murrah	74.3	73.5	17.0	9.5
Concentrate 2 to 2.5 kg and chopped wheat straw	*B. indicus*	72.7	73.9	16.5	
	Murrah	80.1	70.9	18.9	
Ground wheat straw	*B. indicus*	74.3	72.3	16.4	
	Murrah	81.2	72.1	18.3	
Water soaked straw	*B. indicus*	65.5	75.0	16.0	
	Murrah	72.9	75.0	17.0	
NaOH treated wheat straw	*B. indicus*	78.6	74.4	15.7	
	Murrah	64.8	74.3	16.1	
Diet with and without linseed oil[3]	*B. indicus*	55.0			
	Murrah	78.0			
With 250 ml linseed oil	*B. indicus*	52.0			
	Murrah	62.0			
A maintenance diet of wheat straw 2.4 kg, fish meal 200 g and urea-molasses liquid feed (2% urea)[4]	*B. indicus*	45.4	62.0	28.1	9.9
	Murrah	44.7	63.7	26.8	9.5
Ad libitum feeding of green forages[5]					
Green maize, milk stage	*B. indicus*	62.0	79.7	12.6	7.7
	Murrah	62.0	78.1	12.5	9.4
Green cowpea, flowering	*B. indicus*	73.0	79.7	13.2	7.1
	Murrah	87.0	75.6	13.9	10.5
Green maize, milk to dough[6]	*B. indicus*	54.0	66.4	22.3	11.3
	Murrah	53.9	69.3	22.0	8.7
Green oats, head formation	*B. indicus*	67.2	72.3	18.2	9.5
	Murrah	69.9	68.6	20.0	11.4
Green berseem	*B. indicus*	70.9	73.2	17.8	9.0
	Murrah	73.5	73.4	17.1	9.5

Cont'd.

Table 10. cont'd.

Description of diets	Species	VFA (mmol/l)	Percent composition		
			Acetic	Propionic	Butyric
Green cowpea	B. indicus	67.5	71.9	17.7	10.4
	Murrah	73.5	73.0	20.1	6.9
Oat hay	*B. indicus*	40.1	77.1	15.9	7.0
	Murrah	48.7	77.0	16.8	6.2
Hammer milled sorghum × stubble hay (5.19% CP)[7]	Banteng	72.0	69.5	20.6	9.9
	Brahman cross	74.2	71.2	16.7	12.1
	Swamp buffalo	67.9	71.3	20.4	8.3
Untreated rice straw (RS)	*B. indicus*	80.1	65.7	21.3	13.0
	Swamp buffalo	50.4	71.0	19.6	8.5
Alkali treated RS (ARS)	*B. indicus*	51.4	72.5	17.3	10.2
	Swamp buffalo	79.5	72.4	16.8	10.8
RS (70%) and leucaena meal (30%)	*B. indicus*	80.5	74.5	15.7	9.8
	Swamp buffalo	117.1	79.4	13.7	6.9
ARS (70%) and leucaena meal (30%)	*B. indicus*	86.3	76.2	14.4	9.4
	Swamp buffalo	90.7	75.1	14.3	10.6
Green elephant grass	*B. indicus*	107.9	85.4	11.0	3.6
	Swamp buffalo	42.3	84.1	12.2	3.7
Tropical grasses alone[8]	*B. indicus* cross	69.0			
	Swamp buffalo	64.0			
Tropical grasses and urea 4.7 g/day	*B. indicus* cross	75.0			
	Swamp buffalo	70.0			
Urea 20.3 g/day	*B. indicus* cross	78.0			
	Swamp buffalo	71.0			
Urea 100.7 g/day	*B. indicus* cross	75.0			
Urea 93.1 g/day	Swamp buffalo	76.0			
Rice straw with intact protein or urea supplement[9]	*B. indicus* cross	70.0	76.2	16.8	7.0
	Swamp buffalo	58.0	75.5	18.7	5.8
Mean of four forage diets	*B. indicus* cross	74.0	71.8	16.9	11.3
	Swamp buffalo	47.0	69.9	19.3	10.8
Rice straw (70%) and molasses (30%)[10]	Cattle	80.9			
	Buffalo	99.0			

1. Kahlon et al. (1970), 2. Chaturvedi et al. (1973 a, b, c, d), 3. Varma et al. (1973), 4. Pathak et al. (1973), 5. Upadhyay et al. (1973), 6. Jai Kishan (1974), 7. Moran et al. (1979), 8. Kennedy et al. (1992a, b), 9. Kennedy (1995), 10. Abdullah et al. (1992).

Growth performance of *B. indicus* (Hariana) cattle and Murrah buffalo calves

On diet of wheat straw supplemented with two types of concentrate mixture, comparable gain in body weight of growing male Hariana and Murrah buffalo calves has been observed (Table 11). Weight gain was lower in both species on a diet of a concentrate mixture containing 2% urea, which replaced half the groundnut cake from the concentrate mixture of the control group. Less feed was consumed for each kg gain in body weight in both species, due to the use of urea along with molasses for the partial supply of the protein requirements (Ichhponani and Sidhu 1966). The use of a liquid protein supplement made of molasses, ammonium phosphate and distillery sludge, to partially replace groundnut cake in a concentrate mixture supported better growth and improved feed conversion efficiency of crossbred and Murrah buffalo calves (Seth and Arora 1977). A non-conventional diet of a restricted amount of chaffed green oat (2 kg) supplemented with 600 g mixture of dried poultry droppings and groundnut cake (1:1) and *ad libitum* urea–molasses liquid feed (2% urea) was found to be less palatable for growing Murrah buffalo calves resulting in a lower rate of body weight gain and much higher intake of feed per kg gain in live weight, compared to the performance of growing crossbred calves of similar age (Table 11) (Varma et al. 1980).

Table 11. *Comparison of live weight gain and feed conversion efficiency in cattle and buffaloes.*

Description of diet	Species	Live weight gain (g/day)	Kg DM intake/kg gain		
			Roughage	Concentrate	Total
Wheat straw[1]					
Concentrate without urea and with 1% fish meal and 9% molasses	Hariana	432	7.43	4.52	11.95
	Murrah	490	6.74	3.92	10.66
Concentrate with 2% urea, 2% fish meal and 15% molasses	Hariana	500	6.83	4.0	10.83
	Murrah	533	6.35	3.64	9.99
Wheat straw and conventional concentrate[2]	Crossbred	350	–	–	7.28
	Murrah	238	–	–	11.21
Concentrate containing liquid protein supplement made of molasses, ammonium phosphate and distillery sludge	Crossbred	404	–	–	6.33
	Murrah	358	–	–	7.31
Chaffed green oats 2 kg + dried poultry droppings and groundnut cake (1:1) 600 g + *ad libitum* urea molasses liquid feed (2% urea)[3]	Crossbred	370	–	–	8.29
	Murrah	194	–	–	13.12

1. Ichhponani and Sidhu 1966; 2. Seth and Arora 1977; 3. Verma et al. 1980.

Growth of Hariana and Murrah calves from birth to one year of age

In this study, calves of both sexes were used. The feeding period of 180 days was divided into two phases. During phase I (birth to 112 days of age) the calves were fed a diet of whole milk up to 35 days of age including 5 days of colostrums feeding. Skimmed milk was fed from 8th to 112th day of age and calf starter from 8th to 180 days of age. From 6 month (180 days) of age each calf was fed 0.75 kg concentrate mixture, 3 kg green fodder and *ad libitum* wheat straw up to one year of age. However, no information is available about the intake of wheat straw during the feeding trial. The calf starter concentrate mixture was composed of 30% crushed maize, 30% crushed groundnut cake, 20% crushed gram and 20% wheat bran, fortified with 2% mineral mixture and 1% common salt.

The mean values of changes in live weight, body length, heart girth and height at withers at birth and 1, 3, 6, 9 and 12 month of age are presented in Table 12 for the male and female calves of Hariana cattle and Murrah buffalo. The data on changes in body weight and average daily weight gain (ADG), clearly showed negligence in feeding management of calves during 6 to 9 month of age as evident from the very low value of ADG in both species. The average performance of both species was quite comparable, apart from the superior height of Hariana calves.

Table 12. *Growth performance of Hariana and Murrah calves from birth to 12 months of age.*

	Age of calves in month					
Species and sex	Birth	1	2	3	4	5
Change in body weight (kg)						
Hariana, male	28.6	–	59.9	100.3	117.7	172.4
Hariana, female	24.2	–	60.8	77.2	92.1	138.8
Murrah, male	31.2	38.1	59.6	90.0	106.7	164.3
Murrah, female	26.8	34.9	53.7	82.4	–	163.2
Average daily live weight gain (ADG) (g)						
Hariana, male	–	–	348.0	449.0	193.0	608.0
Hariana, female	–	–	407.0	182.0	166.0	519.0
Murrah, male	–	280.0	358.0	338.0	186.0	640.0
Murrah, female	–	270.0	313.0	319.0	–	449.0
Average body length (cm)						
Hariana, male	60.9	–	83.7	96.8	99.0	113.5
Hariana, female	62.1	–	80.8	91.4	98.5	104.9
Murrah, male	62.7	68.7	77.9	90.9	99.6	112.2
Murrah, female	63.0	68.6	76.3	86.1	–	105.3
Average heart girth (cm)						
Hariana, male	69.3	–	93.0	109.0	117.2	132.0
Hariana, female	65.1	–	92.2	101.5	113.1	129.8
Murrah, male	72.6	77.3	91.2	106.4	114.9	129.8
Murrah, female	71.1	76.9	88.1	104.1	–	131
Average height at withers (cm)						

Hariana, male	73.9	–	88.3	101.1	109.7	115.3
Hariana, female	70.8	–	88.9	97.0	100.9	114.0
Murrah, male	69.9	72.8	80.5	89.1	94.2	105.3
Murrah, female	68.3	73.1	77.7	87.1	–	100.2

Effect of nutrition on behaviour of cattle and buffaloes

There are some distinct behavioural characteristics of housed and grazing buffaloes, which may be advantageous for energy conservation when compared to cattle kept under similar situations (Table 13). All the trials support higher energy economising capacity in buffaloes than the cattle. Probably these are the traits responsible for more preference for buffaloes than the cattle in India.

Table 13. *Behavioural characteristics of buffalo and cattle.*

Buffalo	Cattle
Reaction to solar radiation	
Buffaloes wallow in water during the hot period of the day	Cattle run around aimlessly with the rise in solar heat
In absence of water they will lay in mud	Rarely enters in water and dislike wallowing
In absence of water and mud buffaloes take shelter beneath a tree or any other shed	Never lay in mud
All these are done to reduce stress and thus the loss of energy by reducing panting	Thus causing severe panting resulting high-unwanted loss of energy
Feeding behaviour at stall	
Buffaloes eat for long period	Cattle eat for short period
Grazing behaviour	
Buffaloes move steadily at slow pace resulting in more intake of feed from the same place. Thus energy expenditure on grazing is less	Cattle move faster and graze selective due to which energy expenditure is much higher
Locomotion	
Buffaloes walk at a slow pace to aimed place using minimum energy in locomotion	Cattle mostly move aimlessly spending more energy for wasteful movement
Resting	
Buffaloes spend more time resting	Cattle spend less time resting
Aggressiveness	
Buffaloes spend more time resting	Cattle are mostly active and aggressive
Sustainability of milk production	
Lactation period in most of the buffaloes is longer than a year and milk yield often changes with the change in the availability of good quality green fodders	Lactation period in *B. indicus* cows ranges from 3 to 12 months and in most of the cows it is less than 6 months
Buffaloes are less selective in feeding	*B. indicus* cattle are more selective
Buffaloes may live comfortably in crowded herd	Cattle need more open space

Conclusion

From the information presented from comparative studies of feed intake, digestibility and performance, it is rather difficult to draw distinct conclusions as almost all parameters show contradictory results. Therefore, it is necessary to conduct long-term studies with a sufficient number of male and female animals kept on the same diets, management and environment from birth to at least second lactation. Undoubtedly, such studies are expensive and time consuming, but it is only this type of studies that would allow conclusions to be drawn about the relative performance and utilities of the two species of domestic ruminants, which are the backbone of the rural economy in many tropical countries.

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Physiology metabolism and implications for feed evaluation

Undernutrition and realimentation in dairy cattle: Carry-over effects and environmental implications

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Summary

The best use of additionally available feeds is a critical issue in coping with undernutrition in dairy cattle. Situations in which deficient supply will result in undesired carry-over effects in other stages of the production cycle are described. Physiological studies demonstrated that cows have a great ability to restore performance in subsequent lactations when moderately underfed in previous lactations. This is different within the same lactation when realimentation does not allow return to potential yield without excessive supply. According to several studies, adverse carry-over effects of working on performance and on conception rate can be significantly alleviated by realimentation. However, the kind and extent of response of seriously underfed cows in the tropics is not yet clearly understood. Generally, it seems that cows, particularly indigenous breeds, do not respond in performance to additional feeds as would be expected according to nutrient-response models. This paper also summarises the relationship of undernutrition/realimentation and environmental issues. Refeeding could be useful to reduce methane release per kg of milk produced and also to improve the fertiliser value of the manure. One important way to be able to profit in fertiliser value from supplementary feeding is introducing urine capture and field distribution techniques.

Introduction

In many developing countries there is an urgent requirement for an increased milk supply to cope with an expanding human population. The lack of animal products is mostly due to low animal productivity. Causes and effects of undernutrition of cows are known quite well (Chilliard et al. 1995; Kreuzer 1997). The challenge is now to increase productivity using the scarce feed resources in the best possible way. There are periods of increased feed supply, and also governmental programmes give smallholders access to supplementary feeds. However, to make best use of such practical and cost-effective nutritional interventions, it is important to have a better understanding of the causes and extent of response of undernourished cows to additional feed (realimentation). This has to be accompanied by identifying the most sustainable way in terms of low environmental pollution, erosion and desertification. In this respect, differences between indigenous and crossbreds with exotic breeds in response to additional feeds may be of a high relevance. Accordingly, de Haan et al. (1998) defined, in the CEC–WHO–World Bank initiated document, research needs concerning breeds and potential for increased productivity considering traits relevant to lifetime performance. The objective of this paper is to review the state of knowledge on the issues addressed above.

Carry-over effects in dairy cows—Search for the ideal realimentation strategy

Ruminants have developed several adaptive mechanisms in their evolution to cope with undernutrition (Chilliard et al. 1995, 1998) caused by natural fluctuations in feed supply and feed quality. However, most of the knowledge on the response of cows to realimentation is obtained from mildly underfed high-bred *Bos taurus* dairy cattle. Full applicability of these results to cows receiving nutrients at a level at or below maintenance requirements for most of their life remains questionable. Certain physiological reactions might nevertheless be of a general nature thus forming the basis to formulate working hypotheses.

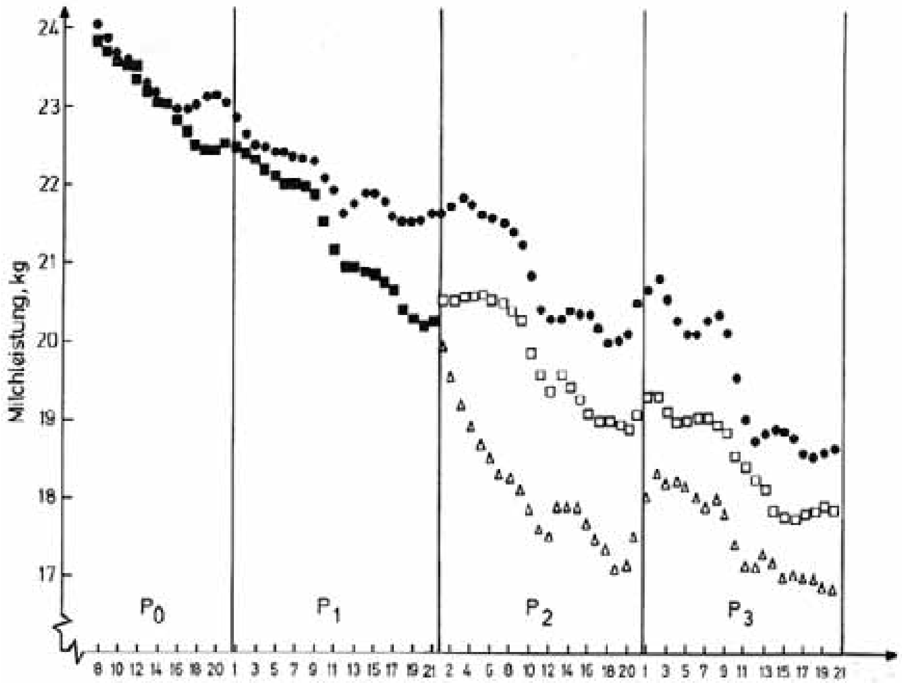
There are a lot of situations when carry-over effects of undernutrition may occur. Generally, this will happen in all periods of undernutrition, which are followed by other critical stages in the production cycle. Selected results on some of these situations are presented below.

Carry-over effects of undernutrition in the dry period on early lactation performance

One of the critical stages of the production cycle of cows is the dry period. Both excessive and deficient nutrition are detrimental to health, conception and early-lactation performance. Mukasa-Mugerwa et al. (1997) stated that: ‘Given adequate energy intake, zebu cattle in thin condition at calving initially replenish body reserves at the cost of lactation’. So, additional available feed resources obviously do not result in an immediate response in milk production. Besides, the value of feed resources spent for this purpose is not directly visible to the farmer although they should contribute to lifetime performance of the cows.

Carry-over effects of undernutrition in early lactation on later lactation performance

A typical response curve of western dairy breeds when mildly underfed (–25% of total protein requirements for maintenance and production) and subsequently refed is illustrated in Figure 1. After an almost continuous decline in milk yield for about a week, adaptation was completed when milk yield was reduced to about half of the amount of protein lacking for potential production level. The residual amount came from body reserves, which are very limited in protein and less limited in energy. When subsequently refed, milk yield will be replenished to a certain degree within a few days. Other than in growing animals, however, lactating cows seem to have a very limited ability to compensate or even over-compensate the depression in milk yield caused by deficient energy and/or protein in subsequent periods of realimentation (Figure 1) (Kirchgessner et al. 1986). Even if the amount of energy, which was not supplied in the period of deficiency, is supplied in a subsequent period, milk yield and milk protein content will only slowly return to that of cows fed constantly according to requirements, and compensation in milk yield cannot be achieved (Kirchgessner and Windisch 1989).



Source: Kirchgessner and Kreuzer (1985).

Figure 1. *Direct and carry-over effects of deficient protein supply (–25% of total requirements) on milk yield.*

Summarising several metabolic studies on realimentation after moderate deficiency of energy and/or protein, Kirchgessner et al. (1987) reported no significant carry-over effects of undernutrition on feed digestibility, nitrogen use, heat production and efficiency of use of metabolisable energy for milk production (k^l) despite clear effects in the preceding periods of undernutrition. Consequently, the carry-over effects on performance should have other causes than an irreversibly impaired metabolic efficiency.

A general observation on response of seriously underfed cows in the tropics to additional feeds was that those underfed for much of their life do not respond to realimentation as predicted by common nutrient-response models (Khalili et al. 1992; Tembani et al. 1994; Osuji et al. 1995). These models assume approximately 2 kg of milk per kg of additional concentrate. Khalili et al. (1982) found in crossbred cows an increase in yield of 0.5 kg per kg of a high protein concentrate independent of the type of forage fed and the initial yield (4.1 and 5.5 kg/day, respectively). The response of very low producing cows to approximately 0.9 kg concentrate (80% maize stover, 15% poultry litter and 5% groundnut tops) was even lower with an average increase of 0.3 kg milk per day. This indicates that indigenous *B. indicus* cows seem to even respond less to concentrate than crossbreds (Tembani et al. 1994). The tropical breeds and high-bred *B. taurus* cattle might have developed different levels of tolerance to undernutrition and pattern of response to additional feeds, in accordance to their degree of exposure to undernutrition. These differences might exist even though no major differences in metabolic use and partitioning of energy could be detected among widely differing types of *B. taurus* breeds (Münger et al. 1996).

Other factors might be important for identifying the ideal realimentation strategy. In this respect, the data of a recent ILRI study (Table 1) suggest a preferential use of protein for restoration of body reserves when energy is simultaneously supplied, and milk yield response is negligible.

Table 1. *Response of indigenous breeds to supplementary protein (cottonseed cake) and energy (molasses) fed on a straw diet.*

Molasses (kg/day)		0			1.9	
Cottonseed cake (kg/day)	1.4	1.8	2.2	1.4	1.8	2.2
Feed dry matter intake (kg/d)	6.7	7.2	7.4	8.2	8.5	8.8
Milk yield (kg/day)	2.8	3.1	3.3	3.1	3.4	3.3
Live weight change (kg/day)	0.0	0.1	0.2	0.1	0.3	0.8

Source: Osuji et al. (1995).

Carry-over effects of undernutrition in the heifer state or in previous lactations on reproduction

Permanently underfeeding heifers delays maturity and, consequently, the expression of first oestrus and conception. Lactating cows seriously underfed will also terminate any reproductive activity, but the ability to restore fertility seems to be principally determined by subsequent realimentation of the cows. Cows which had been underfed to an extent which did not allow any oestrus and conception for two years were found to express first oestrus after 44 days and conception after 63 days when receiving hay and concentrate and getting access to pasture (Zerbini et al. 1996). Without access to pasture, the periods required for expressing the first oestrus and to achieve conception were 83 and 86 days, respectively.

Carry-over effects of previous lactations on performance in subsequent lactations

Multi-lactational studies are scarce. The few available data indicate that cows obviously do not lose their milk production potential when moderately underfed for complete lactations. Cows with initial similar milk yield when underfed in the second and third lactations had the same milk yield in the fourth lactation comparable to a group of cows fed at particularly high level for these two lactations (Wiktorsson 1979). Early lactation weight loss of well-fed cows in the fourth lactation was even higher than the cows adapted to lower feed supply in the second and third lactations. Coulon and Ollier (1996) measured the response to additional energy supply of cows either mildly underfed for four lactations or not. There was no difference in the response of the cows to this energy supplement indicating that undernutrition history plays only a minor role in this case. It remains, however, unclear whether cows, which had never received at least nearly enough feed can, express their genetic potential in milk yield for their whole productive life, when eventually given more feed.

Carry-over effects of work on lactation and reproduction performance

Cows underfed during work at the start of the wet season, i.e. at a time when they are already in thin condition due to feed scarcity in the preceding dry season (Lotthammer 1991), are not able to perform equally well as non-working cows (Table 2) (Zerbini et al. 1993; Gemeda et al. 1995). Supplementary feeding may compensate most of this depression, but supplemented non-working cows were still superior in reproductive performance. The best feeding strategy for working cows is still not completely evaluated as far as the ideal time-point to start with realimentation and the type of supplementary feed (focus on energy and/or protein) is concerned.

Table 2. *Response of working cows to supplementary feeding.*

Supplementary feeding	No		Yes	
Working	Yes	No	Yes	No
Experiment 1[a]				
Oestrus shown (% of cows)	5	61	52	77
Conceived (% of cows)				
–200 days from calving	6	47	40	76
–365 days from calving	16	60	92	100
Experiment 2[b]				
Milk (kg, cumulative) 0–365 days	280	291	355	302
Milk (kg, cumulative) 366–730 days	196	210	307	277

Sources: a. Zerbini et al. (1993), b. Gemeda et al. (1995).

Environmental implication of undernutrition and realimentation

Undernutrition is not only unfavourable with respect to food supply and economic situation of smallholders, but also contributes to environmental problems (de Haan et al. 1998). Underfeeding enhances desertification and erosion. The low nutrient use due to low productivity and fertility increases per unit of food produced and the level of emissions of methane, one of the most active greenhouse gases. Furthermore, feed, which is highly deficient in nitrogen, also reduces the fertiliser value of manure thus enhancing soil depletion. Availability of any supplementary feeds may alleviate these constraints in most cases.

Contribution of undernutrition in livestock to desertification and erosion

There is a problematic cause–effect relationship between undernutrition and desertification/erosion. Increasing demand for cash crops reduces pasture areas and increases undernutrition in livestock. Consequently, the percentage of soil open to erosion increases. Furthermore, undernutrition leads to overgrazing of the remaining scarce pastures. These overgrazed areas are more susceptible to erosion (tread damages) and degradation (weed, loss of biodiversity) than pastures with a lower stocking density. Another consequence of undernutrition may be terminating grazing, and the abandoned land tends to get further degraded. Restoring abandoned pastures in future periods often proves to be very difficult.

Effects of undernutrition and realimentation to methane emissions

In the state of feed scarcity most feed energy comes from fibre. Replacement of 40% of pure cellulose by starch in a diet containing 70% cellulose reduced methane release of sheep from 14.9 to 8.7 g/day (–42%; Kreuzer et al. 1986). When expressed as methane per kg of digested organic matter, i.e. the amount of nutrients contributing to energy supply in the animal's metabolism, even a reduction of 51% occurred by this dietary measure. This illustrates that a high-fibre diet enhances methane release per kg of milk in a three-fold manner: (i) by fermenting fibre, (ii) by low productivity and (iii) by low digestibility of fibre (methane per kg digested organic matter increases). A substantial increase in the supply of starchy concentrates (cereals etc.) for smallholders suffering from feed scarcity seems unlikely to be achieved in a general sense. So, efficient realimentation strategies will have to comprise ways to increase productivity by increasing digestibility of high-fibrous feeds. Ammonia or sodium-hydroxide treatment of straw (Moss et al. 1994) and urea supplementation (Huque and Chowdhury 1997) might be at least partially efficient in this respect. However, due to the general lack of food, an increase in production will nevertheless increase total methane output. In order to selectively suppress methane release from rumen fermentation, certain secondary plant constituents, which could be supplied for instance in the form of multi-purpose trees (Odenyo et al. 1997 a, b; Hess et al. 2001), might be promising. For further considerations on the relationship of undernutrition and methanogenesis see Kreuzer (1997).

Realimentation as a strategy to increase fertiliser value of manure

Undernutrition of dairy cows with energy and protein was demonstrated to reduce both performance and fertiliser value of the manure even in moderate deficiency (Table 3). Since this gap in the nutrient cycle enhances the severity of undernutrition due to the reduced grass and crop growth, strategies to increase the fertiliser value of manure could be very efficient in coping with undernutrition. In this respect, Tanner et al. (1995) suggested applying specific feeding strategies in order to increase the fertiliser value of animal excreta. The fertiliser value of manure depends on:

- its content of the most limiting plant nutrient (N or P or others)
- its proportion of easily-available nitrogen (ammonia N which equals more or less urine N)
- urine capture and field distribution when animals are housed and not kept on pasture
- the coincidence of the sites of nutrient intake and excretion.

A higher N input from feed will usually selectively increase urinary N whereas faecal N output remains widely constant (Kirchgessner et al. 1991; Valk 1994; Kröber et al. 2000). Therefore, any supply of additional nitrogen imported into the livestock production system in the form of feed (e.g. urea-mol asses blocks, poultry litter, oilseed meals) or mineral fertiliser increases the fertiliser value of manure, but only when urine is captured. Improving pastures by introducing the nitrogen-assimilating legumes (Hess et al. 2002) could be similarly efficient as nitrogen importation, and here urine is more or less excreted at the point of demand although sometimes unevenly. Finally, increasing forage quality will elevate the plant nutrient density in manure of cows fed these forages because of the lower excretion of organic matter with manure due to the higher digestibility of the mineral-free carbohydrates.

Table 3. Effect of underfeeding of cows with energy and protein on nitrogen utilisation and fertiliser value of manure.

Nutritional status	As recommended		Deficient by 25%
N-intake (g/d)	436	***	323
Milk-N (g/d)	175	***	136
Manure-N (g/d)	252	***	189
Faeces-N (g/d)	170	***	131
Urinary-N (%)	33		31

*** = Significant at $P < 0.001$.

Source: Sutter and Kreuzer (1995).

Conclusion

To be able to use any additionally available feed resource in the best way in terms of maximum dairy cow response and minimum environmental harm, detailed knowledge on digestive and metabolic function at each physiological stage (productive and non-productive) of the cow's life is required. The state of knowledge in the field of undernutrition and realimentation still has several important gaps:

- carry-over effects of undernutrition in tropical dairy cow systems are highly diverse and poorly understood
- strategies have to be developed to maximise the response to realimentation in performance and fertility
- long-term response of cows to refeeding has to be quantified and communicated to the farmers in order to increase adopting new feeding strategies
- undernutrition has serious negative environmental consequences, which can be alleviated by various, and differing feeding and manure handling strategies.

To be able to increase the knowledge on the response to additional feeds, strategic research has to be carried out. As a first activity of the new ILRI research mission on undernutrition in ruminants, a collaborative project of ILRI and the Institute of Animal Science of the Swiss Federal Institute of Technology (ETH) within the frame of activities co-ordinated by the Swiss Centre of International Agriculture (ZIL) was started in 2000. The project named 'A comparative evaluation of response to and carry-over effects of undernutrition in indigenous tropical and western dairy breeds' addresses some of the issues identified to be of particular interest. A specific emphasis is put on identifying the ideal ‘ecotype’ (A. Speedy, personal communication), i.e. indigenous or crossbred (indigenous × exotics), depending on the undernutrition history of the animals.

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Undernutrition and digestion in ruminants

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Summary

The negative relationship between intake and digestibility of a diet has been widely described. The review of the different processes of ruminal digestion shows that the main cause of the variation in digestibility is the retention time of particles in the rumen. However, most experiments have been carried out at levels of intake higher than maintenance. For this reason, special attention is paid to experiments carried out at low levels of intake. In these conditions, the response of digestibility to a decrease in intake is variable: it can increase, be stable or decrease. Until now, it has not been possible to determine the animal or nutritional factors which influence this variation, especially the unexpected decreases in digestibility. However, it has been clearly shown that these decreases are not due to an insufficient retention time of particle in the rumen, or to an insufficient reduction of particle size. Differences in microbial activity have not been exhibited by *in situ* measurements. It is hypothesised, however, that a reduction in bacterial growth, or in the expression of microbial degradation potential occurs at very low intakes.

Introduction

Undernutrition in ruminants occurs frequently in different countries. In temperate areas, it is mostly of moderate extent, and sometimes due to an economic strategy: when food is expensive (concentrate supply, preserved forages) animals are underfed, the animals are refed when food is available and cheap, as pasture. In tropical countries, underfeeding can be severe and it is generally not controlled. Lack of forage is the main reason for underfeeding, but it may also be caused through the low quality of forages, the depressive effect on intake of high temperatures, or through the effect of water starvation on voluntary intake (Morand-Fehr and Doreau 1998). Infections may also have an effect (Akinbamijo et al. 1997) as well as a long time in search for food also reduce voluntary intake. On the contrary, in case of a lack of available food, animals are fed below the level of their voluntary intake. The consequences of these types of restriction are developed here. Indeed, ruminants are able to cope with underfeeding through mobilising body reserves; however, the metabolic mechanisms of adaptation are limited (Chilliard et al. 1998). The possible adaptations of the digestive processes are not well known.

General relationship between level of intake and digestion

Numerous experiments carried out over more than four decades have clearly shown a negative relationship between the amount of food consumed and digestibility, when diet composition does not change (e.g. Galyean and Owens 1991; Chilliard et al. 1995). This relationship is observed in both sheep and cattle, and is more pronounced when concentrate levels are high. This has been assessed by direct comparison (Colucci et al. 1989) and is confirmed by a global analysis of results available in the literature, based on 253 diets from 70 publications (Figure 1). A difference between sheep and cattle is evident only when diets contain more than 60% concentrates, the variation of digestibility with intake being curiously higher for sheep than for cattle. The contrary was expected, because with diets rich in concentrates, starch digestibility is lowered at high intakes in cattle (Doreau and Rémond 1982) but is always high in sheep. The relationship between digestibility and intake is a consequence of modifications of the extent in ruminal digestion (Michalet-Doreau et al. 1997).

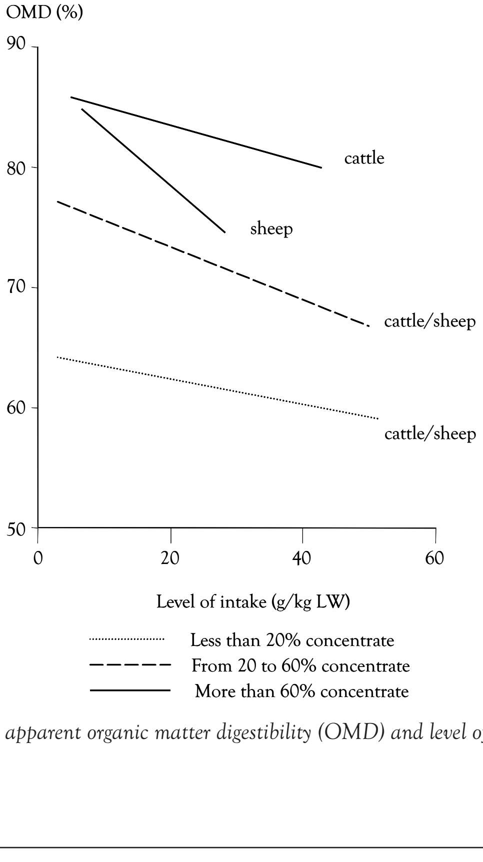


Figure 1. *Relationship between apparent organic matter digestibility (OMD) and level of intake in sheep and cattle: Integration of literature data.*

Ruminal digestion of a diet depends both on microbial activity and on the time of contact between microbes and particles. Microbial activity is the result of the intrinsic activity of bacteria and protozoa, and of feed structure, that is, for the same diet given in different amounts, of particle size, which contributes to determine the microbe–particle interaction. A decrease in feed intake results in more efficient mastication, and a longer period spent eating and ruminating per kg ingested feed (Luginbuhl et al. 1989). As a consequence, ruminal particle size decreases (Okine and Mathison 1991). The surface of attack by microbes increases and the structure of feed is more damaged by chewing. On the other hand, the intrinsic activity of microbes, which depends mainly on rumen environment, is largely not modified by intake. This is shown by the low variations in *in situ* organic matter and fibre degradation of the same forage (Aitchison et al. 1986; Weisbjerg et al. 1991). Conversely, protein degradability seems to increase when intake decreases, as shown by direct measurements of nonmicrobial protein duodenal flows (Punia et al. 1988) or by *in situ* rumen measurements (Zhao et al. 1993). Bacterial concentrations tend to decrease with a decreased intake of available energy (Dehority and Orpin 1988), but in this review the variations in amount of available energy were due to modifications in diet composition, and not intake level. Protozoa population seems to be highest at medium intake, but an interaction between response to intake and concentrate proportion in the diet may occur (Kreikemeier et al. 1990; Punia and Leibholz 1994).

There is a clear negative relationship between level of intake and the ruminal particles retention time in sheep and cattle, whatever the percentage of concentrate in the diet. This can be explained by a moderate variation in the ruminal pool of particles, so that the variation in particle outflow from the rumen has to be achieved by a variation in the rate of passage. Of 33 publications concerning 64 diets, only few of them (Ulyatt et al. 1984 and Peyraud et al. 1989 in particular) did not find any relationship between intake and retention time of particles. This has been attributed to the concomitant increase in intake and rumen volume in these experiments, so that an increase in particle outflow from the rumen does not result in an increase in particle outflow rate. In some experiments (Luginbuhl et al. 1994), the variation of passage rate with intake did not result in a variation in digestibility. It can thus be hypothesised that the passage rate at the highest intake was enough to optimise feed degradation. At the same time, ruminal outflow rate of liquid varies in the same way as intake (Prigge et al. 1984 among others) but variation in intake does not modify liquid outflow rate, probably in relation with the absence of modification of water intake.

When level of intake decreases, pH generally moderately increases (15 publications), sometimes remains constant (9 publications) and occasionally increases (1 publication), whereas volatile fatty acid (VFA) concentration decreases, these two phenomena being related. The causes of the low decrease in VFA concentration when feed intake strongly decreases are shown in Figure 2. In particular, the decrease in both liquid outflow rate and in absorption rate when intake decreases (Doreau et al. 1997) contributes to a longer stay of VFA in the rumen. When intake decreases, the proportion of propionate in the VFA mixture generally increases. This trend is more pronounced when diets are rich in concentrates (Merchen et al. 1986).

The influence of intake on microbial synthesis efficiency, i.e. the ratio between protein synthesis and fermented organic matter, has been measured in at least 19 trials but has not been clearly established, perhaps owing to methodological difficulties. A quadratic response could be assumed from the synthesis of Clark et al. (1992), efficiency being highest at medium intake. Decreasing levels of intake and thus of both energy and nitrogen (N) supply could theoretically increase urea pool, due to the catabolism of amino-acids used as an energy source. In fact, few modifications of the ratio between duodenal N flow and N intake are observed, this ratio being considered as an indicator of urea recycling. This variability of ammonia production and use with intake explains why the effect of intake on rumen ammonia concentration is erratic: ammonia originates from protein degradation, urea recycling, and bacterialysis, and disappears from the rumen through protein synthesis, absorption by the rumen wall and passage through the rumino-reticular orifice.

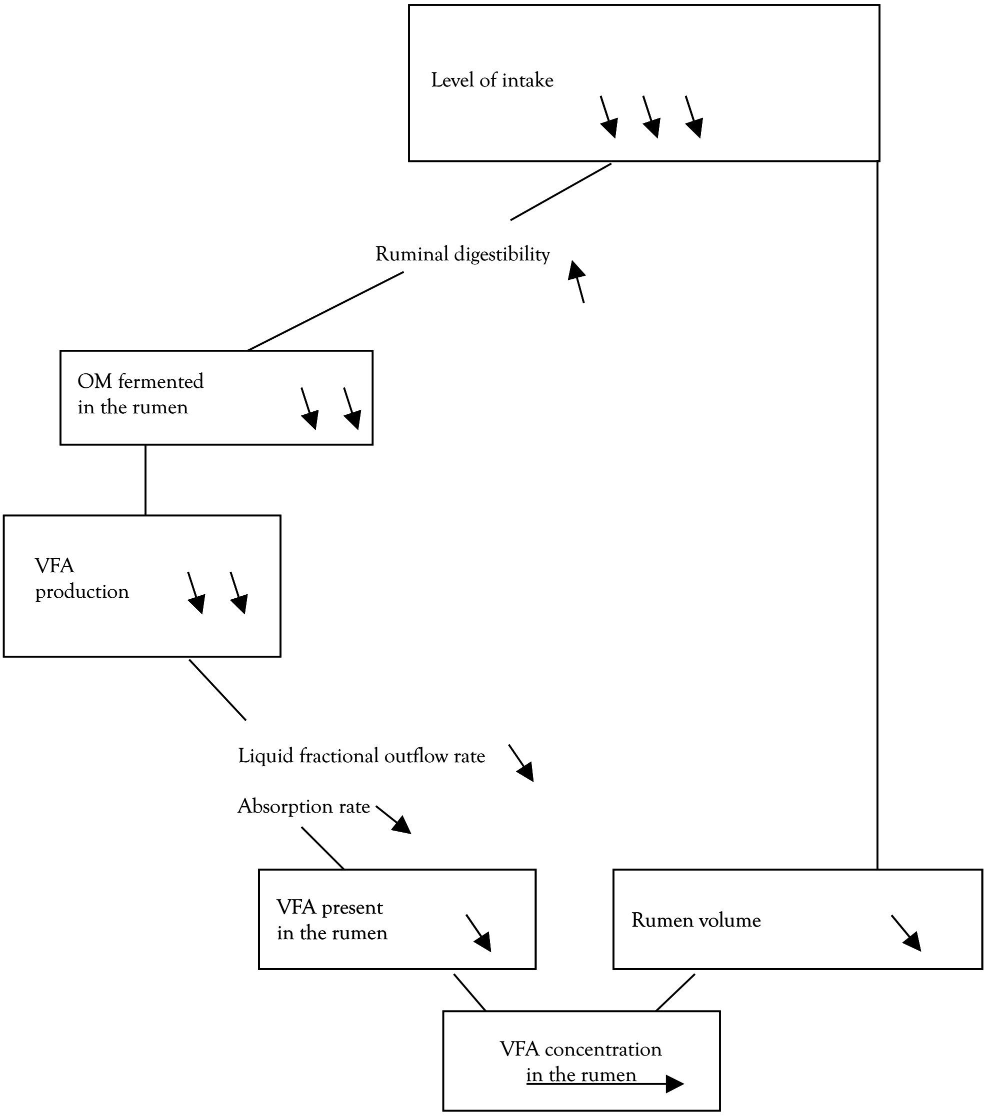
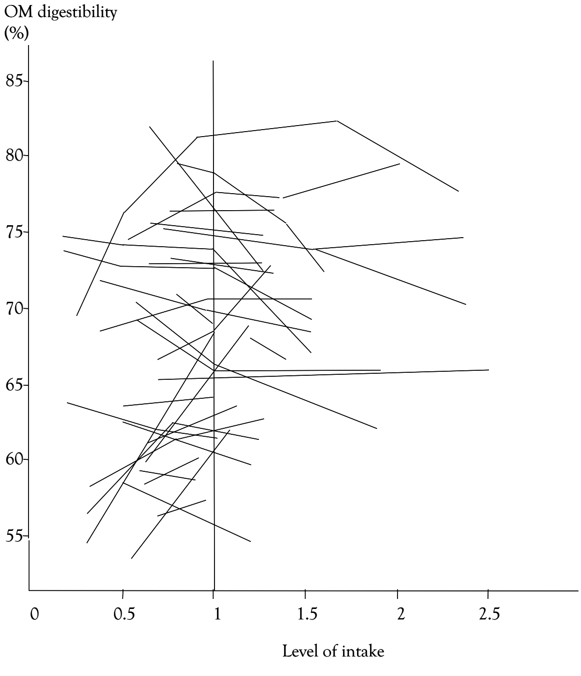


Figure 2. *Factors affecting VFA ruminal concentration when level of intake decreases.*

Variations in digestibility at low intakes

The above shown relationships have been observed in different types of animals, sheep at maintenance, growing steers and bulls, and dairy cows. The majority of experiments have been carried out at levels of intake higher than maintenance. The nature of these relationships at low intakes can be determined only from a small amount of data. Figure 3 clearly shows that results obtained above maintenance cannot be transposed at lower levels of intake. For forage-based diets, very different responses of organic matter and fibre digestibility are observed. In some cases, the same trend as over maintenance requirements is observed (for example Kabré et al. 1995). In other cases, some modifications occur, with slight increases (Michalet-Doreau and Doreau 1999) or decreases (Grimaud and Doreau 1995). The most surprising results are drops in digestibility, observed in different conditions in cattle in West Africa (Grimaud et al. 1998, 1999), in sheep in North Africa (Atti et al. 2002) and in cattle in France (M. Doreau, B. Michalet-Doreau and G. Béchet, unpublished). It could be hypothesised that at very low intake the proportion of endogenous materials in faeces increased, especially with low-quality forages, which could have an abrasive effect on gut mucosa. This could partially explain the decrease in organic matter digestibility, but not the decrease in fibre digestibility.



Sources: Lassiter et al. (1958), McGraham (1964 a, b, c and 1969), Keenan et al. (1969), Leaver et al. (1969), Nicholson and Sutton (1969), McGraham and Searle (1972), Grovum and Williams (1977), Gingins et al. (1980), Doreau et al. (1986), Bines et al. (1988), Ortigues et al. (1993), Agabriel et al. (1995), Grimaud and Doreau (1995), Kabré et al. (1995), Perrier and Doreau (1995), Ortigues and Vermorel (1996), Grimaud et al. (1998), Grimaud et al. (1999), Michalet-Doreau and Doreau (2001), Grimaud and Doreau (2003), Doreau and Diawara (2003), M. Doreau, B. Michalet-Doreau and G. Béchet (unpublished). Results of Atti et al. (2002) are not plotted on this graph: OMD was 59 and 40% at levels of intake of 1 and 0.2, respectively. The level of intake is defined in comparison with level 1 corresponding to the intake allowing to meet energy maintenance requirements.

Figure 3. *Variations in organic matter digestibility with intake: Selection of experiments in which at least one level of intake was lower than maintenance.*

Few experiments have been carried out with high-concentrate diets given at very low intakes. On 80% concentrate diet, Gingins et al. (1980) showed a strong decrease in digestibility when intake was reduced to 20% of energy requirements. Conversely, Doreau et al. (1986) observed an increase in digestibility when the intake of a diet based on 70% maize silage and 30% concentrate was reduced to 70% of maintenance requirements. It does not appear, therefore, that the proportion of concentrates interferes with the response of digestibility to intake variations below maintenance.

It can be asked what determines these unexpected decreases in digestibility when intake is very low. From experiments summarised in Figure 3, it can be deduced that:

- it happens both in sheep and cattle, and as well in zebu as in adapted taurine genotypes
- it is frequent for very low intakes (less than 50% maintenance requirements) although it is not always the case (Michalet-Doreau and Doreau 2001)
- it seems to be independent of nitrogen supply to the animal (intestinal digestible proteins) and to microbes (ruminal fermentable nitrogen), and may happen with concentrate-rich diets
- it could be favoured by a low-quality forage (Table 1).

Table 1. *Effect of underfeeding on organic matter digestibility in Holstein cows receiving either a good-quality hay or a medium-quality hay at three levels of energy requirements.*

	Level of energy requirements (%)		
	154	96	38
Organic matter digestibility (%)			
Good-quality hay	74	74	72.1
Medium-quality hay	65	66	60.1

Source: Doreau and Diawara (2003).

Unfortunately, most of the authors who have carried out experiments at low intake did not perform measurements of digestive processes in the rumen.

To determine possible adaptations of animals with time, and the reversal of this drop in digestibility, several experiments have been carried out with a design in which animals were first underfed, then refed (Figure 4). Several cases have been observed. In two trials (Grimaud and Doreau 1995; Grimaud et al. 1998), the lower the decrease in digestibility, the more an increase was observed after some weeks of undernutrition. In a trial carried out by Atti et al. (2002), severe underfeeding resulted in a significant decrease in digestibility, which remained constant throughout the underfeeding period. In both cases, digestibility after refeeding was close to the initial value before underfeeding. Conversely, in the trial by Perrier and Doreau (1995), underfeeding resulted in an increase in digestibility. Increases in digestibility were also observed after refeeding. Although the results of these experiments are not easy to explain, the need to take into account time effect is clear. This is not frequent in digestion trials.

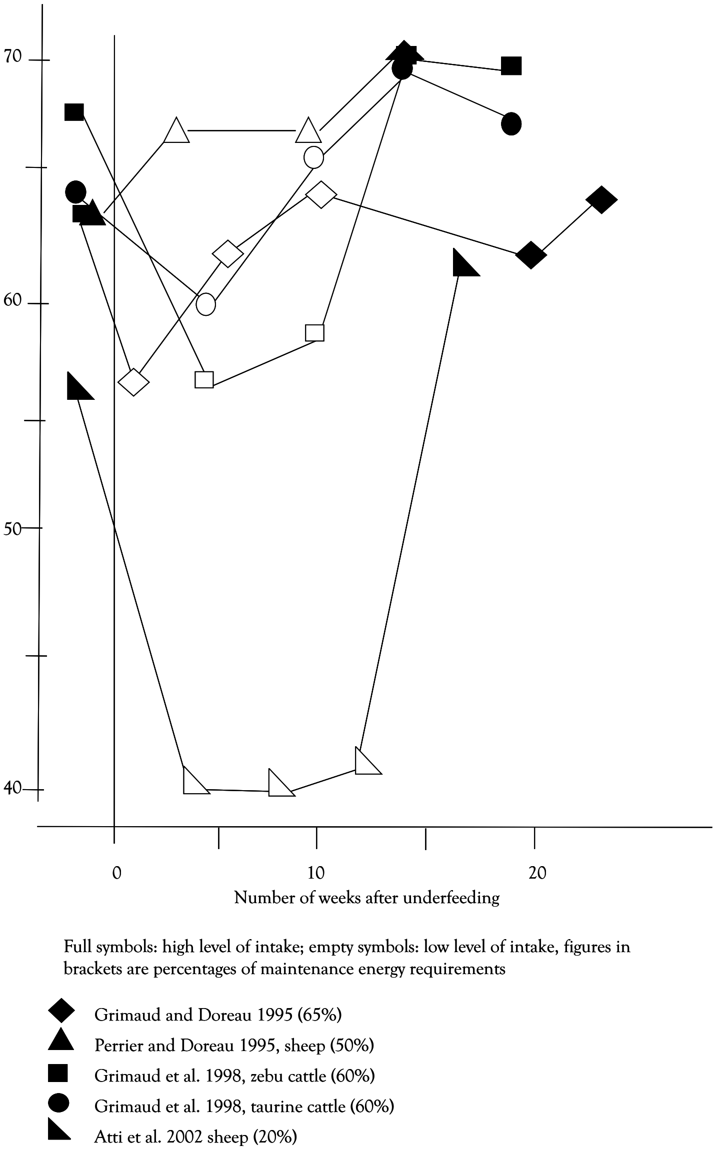


Figure 4. *Effect of a sequence underfeeding–refeeding on organic matter digestibility: Summarising four experiments.*

Specificity of digestive processes at low intake

Absence of effect of particle retention time on digestibility at low intake

Decreasing intake under maintenance level does not involve any increase in ruminal particle retention time (Grimaud and Doreau 1995). This is not characteristic of low intakes since it has also been observed at higher intakes, as mentioned above. However , the general trend is that the more intake decreases, the more ruminal particle retention time increases (Grovum and Williams 1977). In some cases, a very low intake has led to a very long stay of feed in the rumen, showing a curvilinear relationship between these two variables (Table 2) (Doreau et al. 1986).

Table 2. *Effect of underfeeding on the retention time of particles and rumen contents in Holstein cows receiving a hay diet at three levels of energy requirements.*

	Level of energy requirements (%)		
	154	96	38
Retention time of particles in the digestive tract (hrs)	60.0	66.9	87.0
Retention time of particles in the rumen (hrs)	32.2	34.7	53.2
Total rumen content (kg)	104.0	96.7	68.0
Dry rumen content (kg)	9.62	7.5	4.66
Dry matter in rumen content (%)	9.29	7.71	6.88

Source: Doreau and Diawara (2003).

In the experiments where low intakes resulted in a decrease in digestibility, particle retention time, when measured, increased (Grimaud et al. 1998, 1999). A very low intake (20% of energy requirements) has even led to a very long stay, twice than when fed at maintenance, whereas digestibility decreased seriously (Atti et al. 2002). It is possible to conclude that, contrary to results obtained above maintenance, particle retention time in the rumen is not involved in modifications of digestive efficiency. It is likely that at intakes below maintenance an increase in ruminal particle retention time does not contribute to a better digestibility because at maintenance this retention time is long enough to optimise microbial degradation.

A very liquid rumen content at low intake

Contrary to what happens at high intakes, decreasing intake under maintenance level is accompanied by a decrease in total and dry rumen contents: ruminants are not able to maintain a high fill of the rumen. Table 2 illustrates this curvilinear response. At the same time, the contents become very liquid. The possible consequences of such characteristics of rumen contents may be related to an increase in viscosity, and may contribute to disturbances in digestibility.

Combination of particles in the rumen is efficient at low intakes

Underfeeding does not modify to a large extent rumen particle size or faecal particle size, which reflects the size of particles leaving the rumen (Table 3). This lack of variation when intake decreases occurs despite the increase in time spent chewing per kg dry matter intake (Grimaud et al. 1999). However, Ortigues et al. (1993) observed that reducing intake decreased time spent eating and increased time spent ruminating per kg dry matter, so that time spent chewing 1 kg dry matter was not modified. Changes in chewing at low intake were observed with a diet based on maize silage and concentrate and were characterised by a kind of pseudo-rumination due to a too low amount of particles in the rumen (Doreau et al. 1986). This had been previously observed in fasting sheep (Welch and Smith 1968). It thus seems likely that the reduction in particle size when intake decreases is less marked below maintenance than above maintenance. However, apart from extreme cases, an insufficient reduction of particle size in the rumen cannot explain the decrease in rumen digestibility at low intake.

Table 3. *Effect of underfeeding on the ruminal and faecal mean particle size at high (H, 100–154% maintenance requirements) and low (L, 33–55% maintenance requirements) levels of intake of a hay diet.*

Type of animal	Intake level	Ruminal mean size (μm)	Faecal mean size (μm)
B. taurus (Baoulé)[1]	H	1418	
	L	1550	
B. indicus (Peulh)	H	1518	
	L	1238	
B. indicus (Peulh)[2]	H	1821	720
	L	1906	669
B. taurus (Holstein)[3]	H	2117	345
	L	2387	272
B. taurus (Charolais)	H		356
	L		252

Sources: 1. Grimaud et al. (1998), 2. Grimaud et al. (1999), 3. Doreau and Diawara (2003).

Hydrolytic activity of microbial ecosystem is little modified

When intake decreases, *in situ* degradation of forage NDF is not modified (Table 4), except a decrease in undegradable fraction compensated for by an increase in rapidly degradable fraction (Kabré et al. 1995). However, fibrolytic activity of ruminal micro-organisms into bags does not always reflect variations in the whole rumen, due to problems of exchanges between rumen digesta and bag, including both input of ruminal milieu and output of fermentation end-products (Nozière and Michalet-Doreau 2000).

As solid-adherent micro-organisms are known to constitute the most important (Craig et al. 1987) and the most active (Martin et al. 1995) rumen microbial population with regard to microbial mass and fibrolytic activity, modifications of this microbial population according to underfeeding was preferentially studied. Solid-adherent micro-organisms pool size, measured by microbial marker, decreased when intake decreased (Michalet-Doreau and Doreau 2001), in response to a decrease of incoming nutrients. But when expressed per g of rumen content, the solid-adherent micro-organisms concentration is not modified by feeding level. Variations of fibre degradation are not related to modifications in microbial particle concentration, but rather to an alteration in fibrolytic activity of microbial population. Effect of underfeeding on the activity of polysacharidases and glycosidases of solid-adherent micro-organisms has been studied in two trials. Both showed no variation in total activity, in terms of the amount of substrate degraded per g of rumen content and per unit of time (Kabré et al. 1994; Michalet-Doreau and Doreau 1999). This suggests that the hydrolytic activity of micro-organisms would not be involved in the changes in rumen digestion. However, decreased intake resulted in an increase in digestibility (Kabré et al. 1994), and in a trend to an increase in digestibility (Michalet-Doreau and Doreau 1999). Unfortunately, the measurement of fibrolytic activity in adherent population of rumen contents has not been performed in experiments where a decrease in intake resulted in a decrease in digestibility.

Table 4. *Effect of underfeeding on* in situ *NDF ruminal degradation.*

	Parameters of *in situ* degradation				
	a	b	Und	c	L
1.2 maintenance[1]	6.4	66.6	27.0	0.029	4.0
0.5 maintenance	3.7	65.8	30.4	0.035	4.4
1.0 maintenance[2]	13.8	44.7	41.5	0.031	3.3
0.33 maintenance	3.5	44.2	42.3	0.032	3.2
1.0 maintenance[3]	3.8	68.0	28.2	0.032	–
0.6 maintenance	2.0	68.8	29.2	0.032	–
0.2 maintenance	1.4	73.2	25.4	0.035	–

a. Slowly degradable fraction (%); b. Rapidly degradable fraction (%); Und: Undegradable fraction (%); c. fractional rate of degradation of b (h^{-1}); L: Lag time (hr).
Sources: 1. Kabré et al. (1995), 2. Grimaud et al. (1999), Michalet-Doreau and Doreau (2001).

Protozoa are mainly associated with the liquid phase of the rumen content. Their contribution to plant cell wall degradation in the rumen is less than that of the solid-adherent microbial population, but essential in the first hours after feeding by attacking the freshly ingested particles (Martin et al. 1999). Protozoa concentration in ruminal liquid was lowered as feed intake decreased, and this decrease was associated (Grimaud et al. 1999) or not (Michalet-Doreau and Doreau 2001) with a decrease in digestibility. These variations were more marked for post-prandial than for pre-prandial measurements, and were mainly due to variations in concentrating ophryoscolecidae (Figure 5) (Grimaud et al. 1999). However, when expressed per g of rumen content, protozoa concentration tends to increase when intake decreases (Michalet-Doreau and Doreau 2001). Although hydrolytic activity of protozoal enzymes has not been modified, this suggests that a reduction in protozoal activity is not involved in a decrease in microbial activity at low intake.

Hypotheses for a lower microbial degradation activity

It is almost certain that the low digestibility at very low level of intake is not due to insufficient retention time of the particles or to a too large a size of particles in the rumen.

No evidence has been shown for a decrease of microbial activity, but all avenues have not been explored yet. Several hypotheses can be proposed.

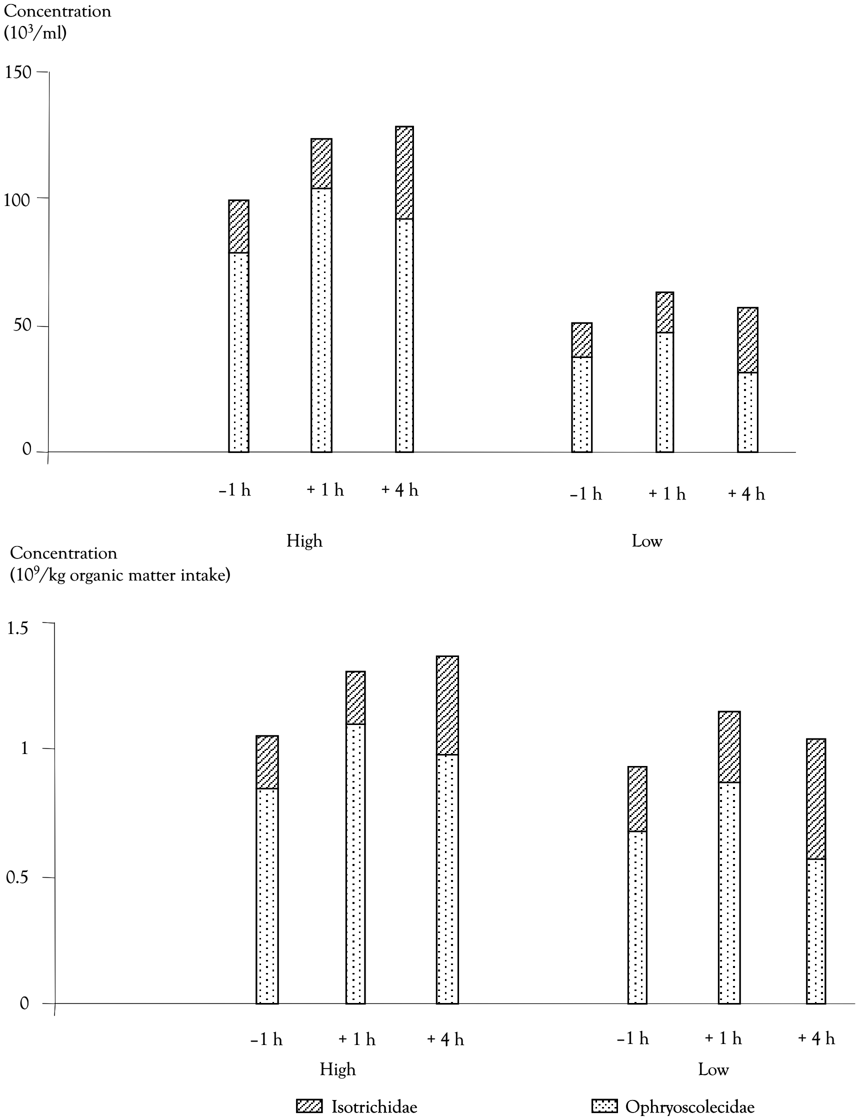


Figure 5. *Effect of level of intake on protozoa concentration before (–1 h) and after (+ 1 h and + 4 h) feeding.*

The first hypothesis is related to a shortage in a specific nutrient for microbes. Besides energy, microbes require fermentable nitrogen, mainly as ammonia but also as amino-acids. A recent experiment showed a decrease in the efficiency of microbial synthesis at low intake (Grimaud et al. 2000). It was suggested in another trial, however, that a shortage in nitrogenous compounds for microbial growth is unlikely, since the level of fermentable nitrogen in the diet does not interfere with the response of digestibility to a decrease in intake, and that nitrogenous compounds in rumen liquid do not seem to be limiting factors (Table 5). Other components as phosphorus and sulphur are known to limit nitrogen growth. Their concentration has not been measured in rumen fluid. It could be hypothesised that phosphorus is not a limiting factor, owing to its high concentration in rice straw, which was the forage used in the trials of Grimaud et al. (1998, 1999) and Grimaud and Doreau (2003); however, phosphorus availability in this forage is not known.

Table 5. *Effect of levels of energy and fermentable nitrogen in the diet on organic matter digestibility and pre-prandial concentrations in nitrogenous fractions in the rumen liquid.*

	HEHN	LEHN	HELN	LELN
Organic matter digestibility (%)	58.8	52.5	59.5	54.8
Ruminal ammonia N (mg/100 ml)	6.0	4.6	5.2	4.1
Ruminal nonprotein nonammonia N (mg/100 ml)	5.6	5.0	6.7	5.5
Ruminal soluble protein N (mg/100 ml)	8.7	9.6	6.1	6.0

Notes: HEHN: high energy high nitrogen; LEHN: low energy high nitrogen, HELN: high energy low nitrogen; LELN: low energy low nitrogen.
Sources: M. Doreau, B. Michalet-Doreau and G. Béchet (unpublished).

A second hypothesis deals with a modification in interrelations between particles and micro-organisms enzymes. Baker and Dijkstra (1999) proposed a model for degradaing substrate including the effective surface area available for enzymatic attack. This new concept is based on aspects of adhesion process, diffusion rate of enzyme in the milieu, micro-accessibility of cell wall to enzyme. In this model, severe underfeeding would induce important changes. The low dry matter content in the rumen of underfed animals could limit the attachment of bacteria to particles because the probability of contact is low, or causes changes in the viscosity of the rumen environment. In other feeding conditions, an increase in viscosity was in relation to a decrease of cell wall degradation (Cheng et al. 1998). Another way to explore this possible modification of adhesion mechanisms is the analysis of soluble calcium in the rumen. Indeed, it has been shown that a lack of calcium limits adhesion and thus digestibility. In a trial where digestibility was lowered by decreasing intake, soluble calcium was not modified by the level of intake (Grimaud et al. 1999).

In conclusion, the variability of the variation in digestibility at low intakes has been evidenced. The influence of some digestive processes has been determined. However, more research has to be carried out in order to predict the digestibility of diets at very low intake. The effect of the type of forage in particular requires more study. At the same time, more analytical experiments have to be carried out in order to determine the possible causes of the changes in microbial activity at low intakes.

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Validity of feed evaluation systems under feed scarcity

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Summary

Scarcity of feed resources is a common problem facing farming systems in the tropics and a major limiting factor to ruminant production. Feed evaluation is an important support to decide how these limited feed resources can be used most efficiently. Under feed scarcity, accurate estimates of the feeding value are essential to predict the potential level of animal production and to decide how to use available feedstuffs with maximum efficiency. A realistic representation of the role of ruminants in the tropical farming systems can only be achieved when accurate feed values and animal requirements are available. To obtain reasonable estimates of metabolisable energy and metabolisable protein requirements of ruminants in the tropics, AFRC equations probably have to be corrected for different components

Introduction

Often, farming systems in the tropics have to deal with scarcity of feed resources, which imposes a strong limitation to ruminant production. Feed evaluation is an important support to decide how these limited feed resources can be used most efficiently. Basically, feed evaluation is a description of the feeds in terms that allow us to predict how much a feedstuff can contribute to the performance of an animal. Under feed scarcity, accurate estimates of the feeding value are essential to predict the potential level of animal production and to decide how to use available feedstuffs with maximum efficiency.

Besides the delivery of animal products, ruminants also play an important role in the cycling of nutrients in the whole farming system. In many developing countries there is a continuous mining of the nutrient stocks in the soil. To investigate the causes of this decline in soil fertility requires an integrated approach. Research projects have been started to monitor and describe the most relevant nutrient flows and its vectors (e.g. Smaling 1993). Ruminants transfer large amounts of nutrients and therefore their role needs to be quantified with the help of feed evaluation systems.

It is often assumed that the availability of energy limits ruminant production and therefore feed evaluation systems for energy are used. One of these systems is the metabolisable energy (ME) system for ruminants (ARC 1980). Much less emphasis is given to the protein supply, which may also be a limiting factor. The protein balance in ruminants can be estimated by the metabolisable protein (MP) system (AFRC 1993). However, both the ME and MP systems were developed for conditions in temperate regions and whether such systems can be applied under tropical conditions requires at least a critical evaluation (Thorne 1993).

From the perspective of the level of the farming system it is easily argued that the description of the role of ruminants should not be too detailed. Efforts to evaluate and improve the ME and MP systems for tropical conditions would hardly add precision in the predicted nutrient flows in the farming systems. However, the higher the impact of ruminants on the nutrient cycles in the farming systems, the more important an accurate representation of the role of ruminants becomes. For example, manure is a major nutrient source for crops and the quality of the manure is an essential aspect that needs to be considered in nutrient cycling. Large seasonal changes and long dry periods will have a large effect on feed availability, feed intake and manure quality (Ayantunde 1998). Does the average of observed manure qualities satisfy the purpose of the modelling effort or is a more detailed estimate preferred for short periods? The level of detail needed in calculating the impact of ruminants on nutrient cycling is completely determined by the purpose of the modelling and the questions that need to be answered. Neglecting good arguments for more detail might very well lead to erroneous conclusions.

A realistic representation of the role of ruminants can only be achieved when accurate feed values and animal requirements are available. To obtain reasonable estimates of ME and MP requirements of ruminants in the tropics, AFRC equations probably have to be corrected for different components (efficiencies, energy allowance for activity, feeding level etc.) based on empirical data. Particularly with the low protein contents in many tropical feeds the possibility of interaction between ME and MP needs to be considered. In this light, evaluating the ME and MP systems seems at least helpful and some of their aspects will be discussed below.

Feed evaluation: Practical problems

Feed characterisation

Accurate feed evaluation is seldom possible in less developed countries as it requires a lot of information about the composition and digestibility of the feeds offered to the animals and about the response of the animals to nutrient intake (Madsen et al. 1997). The paucity of data on feeding value of tropical forages poses a serious limitation to the use of the ME-system. The problem is even more complex with grazing ruminants on tropical pastures where there is a huge spatial and temporal variation in herbage production and quality (Breman and de Wit 1983). This problem is further confounded by the selective feeding behaviour of grazing ruminants. This selective feeding behaviour is observed as animals select feeding or forage station while avoiding certain plant species and showing preference for others (Ayantunde 1998). This selection is also exhibited among plant parts, like leaves, stem, seed and fruit (Stobbs 1973). Because of this, chemical compositions of hand-clipped forage samples are of limited value in feed evaluation (Meissner 1997).

Analytical results obtained in one site may not be applicable in another in view of spatial heterogeneity and seasonal fluctuation in quality of the diet selected by the grazing ruminants. Therefore, in using the ME-system (AFRC 1993) to evaluate the feeding value of tropical forages, simple averages of the chemical composition of available feeds without due consideration to what the animals actually consume may give misleading results.

Specific conditions

An important assumption, inherent in the use of the ME and MP systems (AFRC 1993), is that conditions are ideal and potential limiting factors or stressful conditions are non-existing. However, in tropical systems with extensive feeding or grazing and scarcity of available feed, the defined ideal conditions are not met. Differences between the experimental conditions and practical conditions in the tropics are, among others, a strong fluctuation in feed allowance or in feed quality, higher concentrations of fibre or anti-nutritional factors in the diet, limited and intermittent access to water, and deficiencies in essential factors like macro- and micro-elements. Such differences will reduce the estimated energy and protein value of feedstuffs based on the ME and MP system, respectively.

Not only fluctuating or low feed intake, but also infrequent watering of ruminants affects feeding behaviour, feed digestion and animal energy metabolism (King 1983). For conditions of intense feeding it is well established that higher outflow rates of rumen fluid increase microbial efficiency (Owens and Goetsch 1986). This effect was demonstrated in a study with a sophisticated mechanistic rumen model (Dijkstra et al. 1992). In the study, fermenting protein, starch and sugar was strongly influenced by the rumen outflow rate of water, whereas fibre degradation was strongly influenced by the rumen outflow rate of feed particles. Because water intake is linked to dry matter intake with intense feeding conditions, fluid outflow rates are related to particulate outflow rates (Owens and Goetsch 1986). However, these results were established for constant feed allowance with free access to water and may not be transferable to conditions where intake of feed and water is not directly coupled. During the dry season a low feed intake will be accompanied by low water intake. The latter will decrease volume and outflow rate of rumen fluid.

Infrequent watering of animals will result in sudden extreme increases of the volume and of the outflow rate of rumen fluid, which dilutes the microbial population and causes outflow of micro-organisms from the rumen. The rumen serves the ruminant not only to ferment fibrous feeds but also as a water reservoir (Shkolnik et al. 1979). Such large quantities of water present in the rumen after drinking will affect the activity of the rumen micro-organisms and hence affect rumen digestion of feed. Adapting a ruminant to dry periods is very likely to influence the interaction between the level and frequency of dry matter and water intake, feed digestion and the nutrient supply to the animal. The ME system was not developed to account for the possible consequences of these changes on the energy metabolism of the ruminant.

Besides (rumen) digesting feed, ruminant metabolism can also be influenced by less-ideal tropical conditions. It is well known that water and mineral deficiencies influence milk production by dairy cows. Consequently, a changed partitioning of the metabolisable energy consumed by the animal might be expected too. Potassium or long-term phosphorous deficiencies reduce milk production and feed intake (McDowell 1992; Valk et al. 1999). Heat stress would further add to a water deficiency and a loss of minerals. These limitations might be more compelling for non-indigenous high input–high output breeds that may be expected to be less well adapted.

Many other factors can be thought of which are not relevant in the high input feeding systems in temperate regions but which do impose a serious limitation on animal performance in the tropics. Hence, estimating contributing ruminants to nutrient cycling by the use of the ME calculation rules might give an erroneous impression of the practical situation.

Metabolisable energy

Feed metabolisability

According to AFRC (1993), the efficiencies of use of metabolisable energy (ME) for maintenance, lactation and growth is determined by metabolisability of a feed (q_m) at maintenance. For a reasonable prediction of the energy requirements for maintenance and production, it is then necessary that the q-values of the feeds are known. This is not a problem for temperate forages because data are widely available on their ME contents (AFRC 1993). However, q-values of most tropical forages are unknown (Abate and Mayer 1997). In using ME-system for feed evaluation in the tropics, the common approach is to predict ME values of feeds from regression equations based on models mainly developed from experimental data generated in temperate environment (Abate and Mayer 1997) or assuming a q-value of between 0.5 and 0.6 (Chesworth 1992). The main problem with the latter approach is a huge variation in ME energy content of tropical forages (Chesworth 1992) even though the variation in gross energy content is very low. Thus, q-values can be as low as 0.35 for low quality straw to over 0.7 for high quality ration for use in dairy cattle in the tropics.

Figure 1 illustrates the implication of an incorrect value of metabolisability on maintenance energy requirements (AFRC 1993) for cattle of 250 kg live weight (one Tropical Livestock Unit, TLU). Low quality feeds require more ME intake to meet maintenance requirements of the animal while less ME intake is required with high quality feeds. An over- or under-estimation of q_m by 0.1 results in a 5% under- or over-estimation of the maintenance energy requirements. The question here is: Of what significance is 5% error to applicability of ME system in tropical condition? It has to be remembered that an incorrect value of q_m is only one of the sources of error in ME system. Estimating ME content of a feed from regression equations on feed's chemical composition is another possible source of error, especially where models used are based on temperate condition (Blummel et al. 1997). The analytical approaches developed for feeds of a good quality might not be applicable for feeds of a low nutritive value. It is then important to develop predictive models of ME based on data on tropical forages since the direct measurement of ME in energy balance involves complicated methods and expensive equipment (Chesworth 1992). Slaughtering trials with large animals are also expensive. In case of paucity of data, the models developed in temperate condition can be used but with necessary correction based on empirical data on tropical forages.

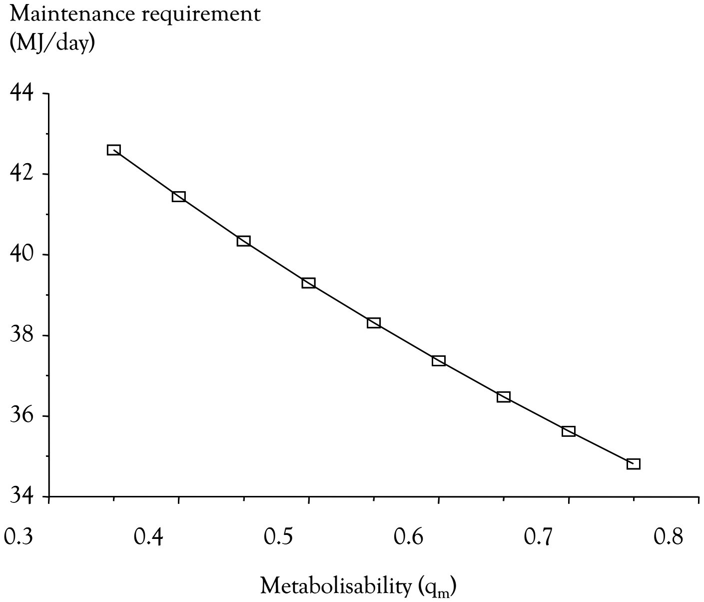


Figure 1. *Relationship between metabolisability of feeds and estimated maintenance ME requirements for a cattle of 250 kg live weight.*

Apart from the problem of unavailability of data on q-values of tropical forages, the use of metabolisability in determining the efficiency of use of a feed is confronted with the problems of accuracy when a given feed is fed to animals in different physiological stage of different species and when fed in different forms (pellet, chopped, ground) or in combination with other feeds (ARC 1980). In addition, there is also the possible influence of season, stage of harvest of forages and anti-nutritional factor on the efficiency of use of the tropical feeds (Madsen et al. 1997). Digestible energy and metabolisable energy values differ between animal species because losses in faeces, methane and urine differ; it is then doubtful if the q-value of a feed is the same for different animal species. Besides, the obtained feeding value of a specific feed is to a great extent determined by the composition of the ration in which it is fed (Madsen et al. 1997). Therefore, assuming additivity of ME (measured at maintenance) of the diet's compound feeds (ARC 1980) may not hold in view of possible interaction of the different nutrients of a ration. Metabolisable energy of feeds also depends on using nitrogen components for processes of protein synthesis (Nehring and Haenlein 1973).

Efficiency of use

In addition to metabolisability of feed, the efficiency of use is influenced by level of feeding (ARC 1980; Madsen et al. 1997). Nutritive value of a feedstuff is dependent on the intake and on the amount of nutrients absorbed from the ingested feedstuff during its passage through the gastro-intestinal tract. For instance, if a growing animal consumes more and more of a given feed, more and more of the ME consumed will be used at a relatively low efficiency for gain. The ME actually available to the animal is reduced significantly at high levels of feeding due to a reduced retention time in the rumen (ARC 1980). For dairy cattle, the decline is estimated by ARC (1980) to be 1.8% per unit increase in feeding level above maintenance ME requirements. This value is used as correction factor for lactating ruminants in ME system (AFRC 1993). However, the question is whether this correction factor established for high producing temperate dairy cattle is valid for lactating cattle, sheep and goat in the tropics. Another question is: How do we correct for the effect of the level of feeding on the efficiency for the animals under feed scarcity? It is reported by Leng (1990) that the efficiency of feed use in ruminants in tropical climate given low quality roughages is higher than prediction from ARC (1980). His observation is supported by the results of experiments carried out in Burkina Faso by Grimaud et al. (1998) that apparent digestibility increased between the beginning and end of undernutrition period by both *B. taurus* and *B. indicus*, suggesting increase in efficiency of use of feeds. Further work in this line is essential for reliably evaluating the feeding value of tropical feeds.

Maintenance energy requirements of tropical animals

There are increasing evidences (Western and Finch 1986; Leng 1990; Ibeawuchi and Akinsoyinu 1991; Schlecht 1995) that ruminants in tropical climate have lower maintenance ME requirements than estimates by AFRC (1993), especially in the dry season. Figure 2 shows the maintenance ME requirements of grazing cattle estimated by Western and Finch (1986) with a mobile technique for respiration measurement and by Schlecht (1995) by regressing energy retention on metabolisable energy intake, compared to AFRC (1993) prediction. The activity of the animals is assumed to be 8 km walk on a horizontal plane. For a 250 kg zebu cattle, AFRC (1993) over-estimated the maintenance energy requirements by between 8 and 20%. Lower maintenance ME requirements was also reported for non-lactating and non-pregnant Friesian cows of about 376 kg live weight in Nigeria (Ibeawuchi and Akinsoyinu 1991), suggesting that the reduction in maintenance energy requirements may be due to adaptation to the climatic condition. Apart from the possible effect of the thermal environment, the energy requirements of the animals may also be influenced by the previous plane of nutrition, health history and most importantly the protein:energy ratio in the absorbed nutrients (Leng 1990). There is also the suggestion by Grimaud et al. (1998) of behavioural adaptation of the animals in the tropics to undernutrition. The over-estimation by AFRC (1993) may also be explained by a rather high energy allowance for activity of 2.6 KJ/kg live weight/km distance when compared with 1.35 KJ/kg live weight/km reported by Rometsch et al. (1994) for zebu oxen in Niger.

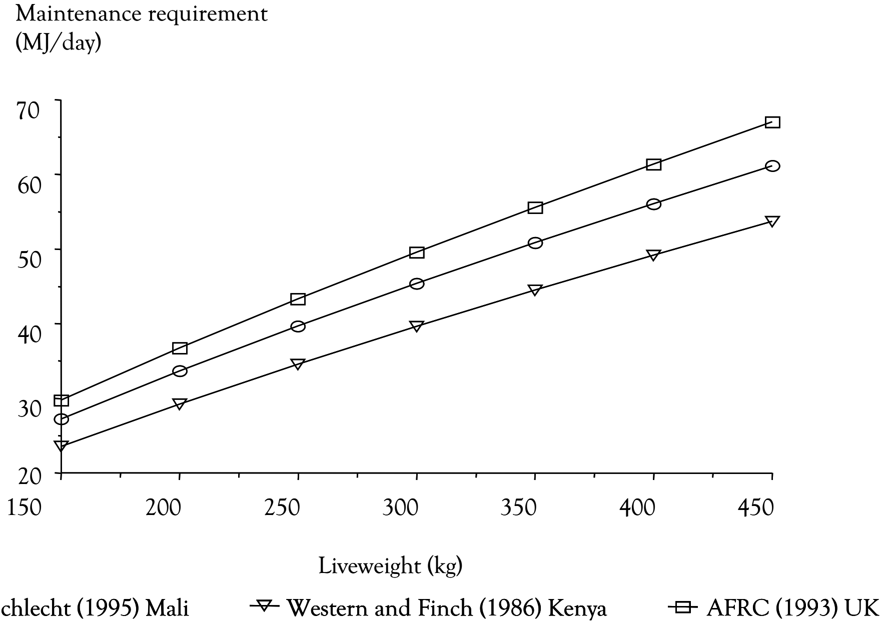
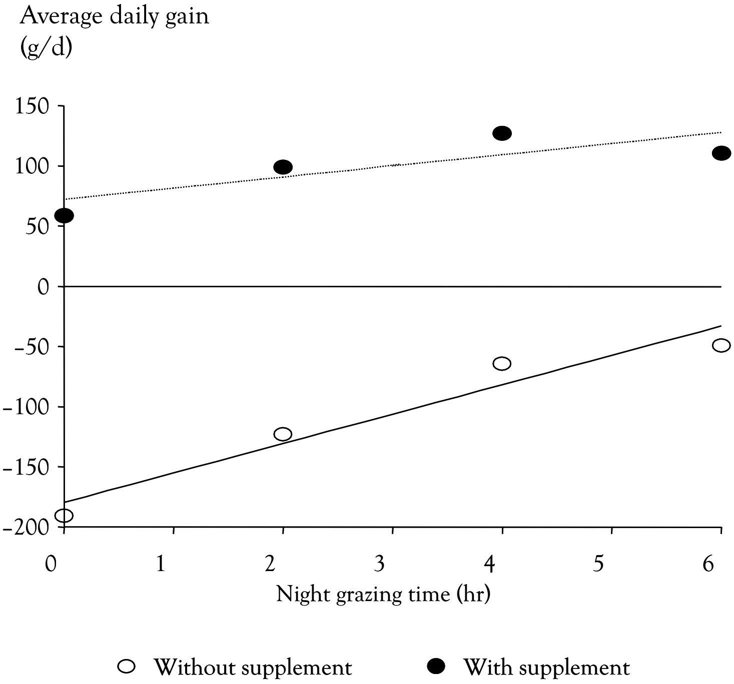


Figure 2. *Estimates of maintenance ME requirements of grazing cattle in tropical climate.*

Mobilising body tissues and the changes in body composition of the animals when under feed scarcity may also explain the lower maintenance ME requirements. Figure 3 further demonstrates that AFRC ME-system tends to over-estimate the maintenance requirements of the ruminants in the tropics. In this experiment (Ayantunde 1998), grazing steers of about 224 kg live weight grazing natural pasture in the dry season were given millet bran (608 g DM/animal per day) to meet the energy deficit of 4 MJ per day based on recommendations by AFRC (1993) for maintenance requirements. It was, however, surprising that all the supplemented animals had a daily weight gain of at least 50 g. The possible reasons for this could be protein:energy interaction which might have improved the efficiency of use of the forages (millet bran had 14% crude protein while the forages grazed had 7%), lower maintenance ME requirements than that recommended by the AFRC (1993), and an incorrect value of metabolisability of the forages (assumed to be 0.5).

Non-ideal conditions in the rumen have a potential impact on feed use by the ruminant. An impaired activity of micro-organisms in the rumen will reduce digestion rates and consequently feed intake. For these reasons, infrequent feeding, low levels of intake, and a discontinuous digestion are undesired. These conditions do normally occur, however, in extensive feeding systems in the tropics. A change in feed intake and in weight of the metabolically active splanchnic tissues will affect whole animal energy metabolism (Ortigues and Doreau 1995). Ortigues and Durand (1995) investigated the adaptation in energy metabolism to undernutrition in ewes and demonstrated that energy expenditure of the splanchnic tissues (digestive organs and liver) was drastically reduced. In a well-fed ruminant these organs are responsible for a large part of the maintenance requirement. Therefore, a severe reduction in energy expenditure with undernutrition may be expected to lower maintenance requirements and hence make the assumptions in the ME system inappropriate. These results are confirmed by the observation that with a change in level of feed intake the previous level strongly determines the maintenance requirement (Baldwin 1995). This seems to hold for various animal species. Such aspects of energy metabolism cannot be neglected in attempts to understand the feed requirements by ruminants. Ruminants are well capable to adapt to extreme changes in conditions and have to do so in many tropical conditions. However, it should not be surprising that under these conditions the energy metabolism differs from that calculated with the ME system.



Source: Ayantunde et al. (1998).

Figure 3. *Average daily gain of supplemented and non-supplemented cattle grazing during the day (for 10 hours) and/or night in the dry season in Niger.*

Metabolisable protein

The MP system (AFRC 1993) is often used to estimate the protein balance of ruminants and also for tropical circumstances. Like most recently developed protein system, the MP system recognises the specific digestive processes in ruminants. In ruminants, micro-organisms in the fore-stomachs degrade a major proportion of the feed. On the other hand, a proportion of that degraded protein will be incorporated into microbial biomass, which flows to the small intestine and is a valuable protein source for the animal. Thus, metabolisable protein is the sum of digestible microbial true protein (DMTP) and digestible undegraded feed protein (DUP).

This system is mainly derived from the results of experiments carried out in the UK. A study of van Straalen et al. (1994) showed that even within Europe the validity of nationally developed feed evaluation systems may be limited to regions. Thus, we may also question whether the MP system is a valid system for regions where practical circumstances are more different from the circumstances in which the MP system was developed. In this section the MP system will be considered in more detail and aspects where differences may be expected between circumstances in which the MP system was developed and circumstances where feed scarcity is common will be discussed.

Available protein at small intestine

Microbial protein production in the rumen depends on the availability of energy, building blocks and the efficiency by which the micro-organisms use these available nutrients. In the MP system the availability of nutrients and the efficiency of their use by the micro-organisms is estimated by taking into account the energy supply to the microbes, the nitrogen supply to the microbes and the level of feeding of the animal.

The energy supply to the microbes is estimated as the amount of fermentable metabolisable energy. Fermentable ME is equal to the ME content corrected for the amount of ME from fat and oils and from fermentation products in feedstuffs. In this approach it is assumed that the carbohydrates and protein is available to the anaerobic micro-organisms in the rumen, whereas the ME in dietary fat, oils and fermentation products is not. Thus, in the MP system no corrections are made for the proportion of carbohydrates and protein that is digested after the rumen. Other systems take into account the proportion of protein that escapes from microbial degradation to calculate the amount of fermentable energy. The DVE/OEB system (Tamminga et al. 1994) also corrects for the amount of escaped starch. None of the present protein evaluation systems take into account a possible shift in the site of digestion within the gastro-intestinal tract. For instance, when feedstuffs with a relatively low total tract digestibility are offered, the site of cell wall digestion shifted from the rumen to the rest of the gastro-intestinal tract (Ulyatt et al. 1975). Consequently, a smaller proportion of that degradation will take place in the rumen and the released energy, estimated from total tract digestibility, will not become available for the micro-organism in the rumen. If we assume that 15% of the digestible organic matter is not available to the micro-organisms a reduction in microbial protein production of approximate 10 g per kg DOM can be expected (Figure 4).

In the MP system nitrogen supply to the micro-organisms is estimated as the amount of N available from protein effectively degraded in the fore-stomachs. The latter consists of 80% of the quickly degradable protein fraction and the total slowly degradable protein fraction. It is assumed that the effectively degraded protein is incorporated into microbial protein with an efficiency of 100%. This is high, but it is also used as compensation for nitrogen supplied from urea that is flowing to the fore-stomachs (partly by saliva). In West European countries where the contribution of urea recycling to N supply is relatively low such an assumption may be permitted. However, under tropical conditions the role of recycled urea N may be more pronounced and could be of more importance. Data on net portal fluxes and on secretion and composition of saliva suggest that approximately 100 g urea N is recycled daily, which under conditions in The Netherlands is 20% of the amount of N entering the rumen by feed. But with much lower N concentrations in the diet the recycling of urea-N may be relatively more important. Digestible undegraded feed protein (DUP) can be regarded as the proportion of feed protein that escapes from being degraded by the rumen micro-organisms. Thus, the actual amount of DUP depends on the retention time in the rumen, the potential digestibility of feedstuffs and the activity of the micro-organisms. Deficiencies in energy, minerals and other essential nutrients for the micro-organisms (Leng 1990) and the presence of micro-toxic anti-nutritional substances may reduce the rate of degradation. On the other hand, a reduction in rate of degradation can be compensated by an increase in rumen retention time.

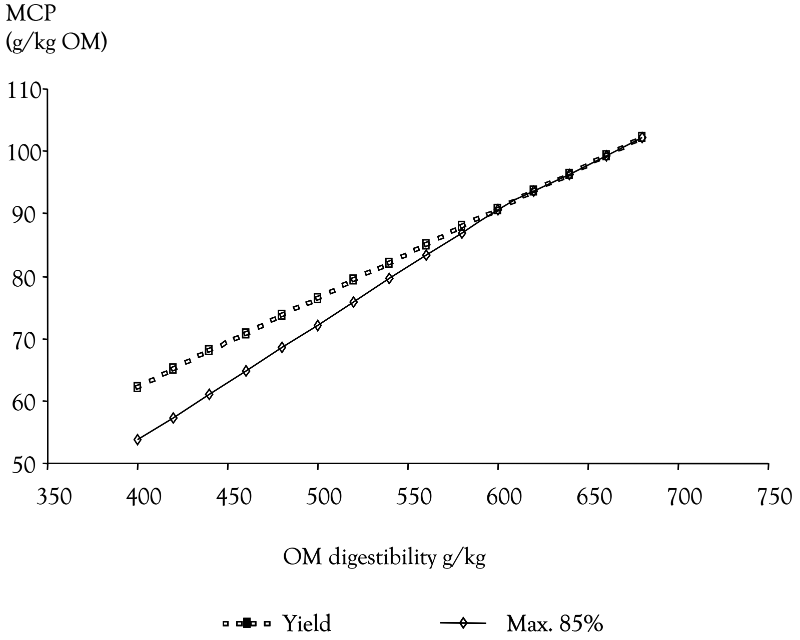


Figure 4. *Estimated reduction in yield of microbial crude protein from a shift in site of digestion from rumen to large intestine of maximum 20%.*

Efficiency of protein use

The level of maintenance requirements and factors that limit the potential use of absorbed protein may influence the efficiency of protein use. Parasites in the gastro-intestinal tract, lungs, liver and blood cells are often accompanied by higher losses of protein as an effect of tissue damages and leakage of macromolecules (van Vuuren 1999). Also the higher activity of the immune system will increase protein requirements.

Leng (1990) emphasised that under tropical conditions with a high temperature humidity index extra protein will be used more efficiently than under thermoneutral conditions. On low quality forages a large proportion of the absorbed nutrients can be regarded as precursors for fat. Because at higher temperatures, oxidising these nutrients should be limited to prevent heat stress, which the animal regulates by reducing feed intake. If such nutrients can be used for growth or milk production these negative effects may be reduced. This hypothesis would explain the relatively high efficiency by which protein is used when supplemented to low quality diets (Leng 1990).

From these examples it is clear that the efficiencies used in the existing protein systems are not valid under tropical conditions.

Conclusion

To make optimal use of the scarcely available feed resources in the tropics, their feed characteristics need to be known. More analytical data are needed for tropical feedstuffs. The near-infra-red spectroscopy can be an accurate and relatively cheap technique. However, such a technique requires a large set of data for calibration. Until now most calibrations are based on feeds different from those in the tropics.

Current regression equations cannot always be applied and new equations need to be developed that allow for a better estimate of the metabolisability of feeds under these conditions. Animal experimentation will be needed to obtain such data. Besides feed, water must also be considered as an important nutrient and the effect of intermittent water intake on feed intake, and on the digestion and use of the feed by the animal probably needs to be given more attention.

Generally, only the metabolisable energy value of feeds is used to predict animal performance. However, in conditions of low protein intake, the amount of metabolisable protein may as well be the limiting nutrient instead of metabolisable energy. For this reason, the effect of energy and protein availability and their particular interaction under conditions of feed scarcity needs to be investigated.

Finally, in studies of nutrient cycling in farming systems, modelling exercises need to be promoted. However, to apply such modelling tools with some confidence, the role of animals must be represented precisely enough to prevent erroneous conclusions. Therefore, current feed evaluation systems need to be thoroughly evaluated and adapted for the specific region or farming system of interest.

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Evaluating tropical forages by a simulation model of nutrient kinetics

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Summary

A dynamic model of digestion and absorbing nutrients is described. It was evaluated and applied in cattle fed sugarcane-based diets. The model contains 18 state variables, and six zero pools representing absorbed nutrients. The rumen state variables represent nitrogen, carbohydrate, long chain fatty acid, microbial and volatile fatty acid pools. The zero pools are related to ammonia, amino-acids, glucose, and volatile and long chain fatty acids. The flux equations are described by mass-action and Michaelis-Menten forms. Wherever possible, data derived from trials with cattle fed sugarcane diets were used to parameterise the model. The model was applied to predict nutrient supply profiles to the host animal from dietary intake, to indicate, pre-experimentally, the suitability of various supplements to enhance cattle production on sugarcane-based diets in the tropics.

Results from model simulation were very consistent showing that the inclusion of cottonseed and soybean meals in the sugarcane-urea diet increased amino-acids supply at the small intestine, more than two-fold. However, microbial protein at the small intestine increased by 11% only. The increased supply of amino-acids was due mainly to the dietary by-pass protein. On the other hand, the same amount of rice meal and maize grain increased total amino-acids supply by 40% only and microbial protein supply by 14 and 34%, respectively. Microbial synthesis was enhanced probably because of the greater supply of less rumen degradable carbohydrate (starch) in these supplements. While supplements increased supplies of amino-acids and lipids more than 40%, energy increased by 26–30% only. After the supplementation for amino-acids, energy seems to be the next nutrient limiting animal production on sugarcane diets.

The present model could be a powerful tool for manipulating the profile of nutrient supply for ruminants in the tropics. Also, it could be applied to evaluate the potential use of crop residues and by-products for the feeding of cattle in conditions of undernutrition.

Introduction

Diet formulation based on digestion kinetics and nutrient flows in the gastro-intestinal tract (GIT) could result in nutritionally sound rations for ruminants (Robinson et al. 1987; Ellis et al. 1988) and suitable data are now available for several tropical feeds in Brazil (Valadares Filho et al. 1990; Aroeira et al. 1996). However, it is difficult to incorporate all the relevant information in a model that could both satisfy the animal-nutrient requirements and be cost-effective. Simulation through mathematical modelling has proved to be a powerful tool to effectively integrate and use current knowledge of digestion kinetics (e.g. Baldwin et al. 1987; Dijkstra et al. 1992). Theoretically, such models can be used to manipulate rumen fermentation and nutrient absorption to improve animal performance.

A model has been built to evaluate supplements for Brazilian dairy cows fed sugarcane diets (Dijkstra et al. 1996). The model seemed to be able to predict rumen ammonia concentration and NDF outflow, but it underestimated non-ammonia nitrogen (NAN) outflow compared to field data. As quoted by the authors, it could indicate the need for accounting for endogenous-protein nitrogen (EPN) sources, such as secreting gastric juices and epithelial cells from the GIT. The model was refined by incorporating a sub-model, which estimates EPN flows in the GIT, as described by Assis et al. (1997). Also, a simple representation of the large intestine has been included in order to account for digestion and absorption, as well as, EPN sources in the hindgut.

The objective of this paper is to present the new version of the model, showing its response to different types of supplementation for sugarcane-urea based diets. The model could be adjusted to evaluate the potential of high-fibre diets for animals in undernutrition conditions.

Model description

The model is based on the principles applied in previous models (Baldwin et al. 1987; Dijkstra et al. 1992), but uses a more simplified structure with some nutrients and metabolites treated as single pools. To represent the GIT by a simple flow diagram (Figure 1), it was split into three compartments, namely: stomach—comprising rumen, reticulum, omasum and abomasum; small intestine—duodenum, jejunum and ileum; and large intestine—caecum, colon and rectum. Basically, the stomach contains twelve ruminal pools or state variables, namely: undegradable protein (RUP), insoluble degradable protein (RDP), soluble protein (RSP), ammonia (AMR), undegradable fibre (RUF), potentially degradable fibre (RDF), water soluble carbohydrates (WSC), volatile fatty acids (VFR), insoluble starch (ISR), lipids (LIR), microbes (MIR) and endogenous protein (EPR). Amino-acids (AA), ammonia (AMS), glucose (GLU) and lipids (LIS) reaching the small intestine are represented as zero-pools, plus a full pool formed by endogenous protein (EPS) from the stomach and small intestine. In the large intestine, six full pools—microbes (MIL), dietary protein (DPL), endogenous protein (EPL), fibre (FIL) and starch (STL) and two zero pools—ammonia (AML) and volatile fatty acids (FVL)—are represented. Minerals and vitamins are not considered and assumed to be non-limiting.

Dijkstra et al. (1996) described in detail the model dynamics. Briefly, the rumen microbial population is assumed to use WSC derived from the diet and from degradation of starch and fibre, and ammonia derived from hydrolysis of recycled urea and dietary N. Protozoa are considered to be a fraction of microbial mass which is selectively retained in the rumen, and they are recycled by death and lysis. The remainder of the microbial pool, formed by bacteria, is passed from the rumen with the digesta flow. After hydrolysis, urea N recycled via the saliva and diffusion through the rumen wall, enters the ruminal ammonia pool. Ammonia N is removed from this pool by incorporation into microbial cells, by absorption and by passage from the rumen. Volatile fatty acids produced in and absorbed from the rumen are aggregated into a single pool. Nutrients available for absorption in the small intestine are: amino-acids derived from microbial and dietary proteins, glucose from dietary starch, WSC, and microbial carbohydrates and dietary lipids.

Two versions of this model have been developed, thus far. In both versions, flux dynamics are represented in a series of equations of the mass-action or Michaelis-Menten form. However, the present version differs from the previously published version (i.e. Dijkstra et al. 1996) in three basic aspects.

Firstly, the previous version was written in Advanced Continuous Simulation Language-ACSL (Michell and Gauthier 1981) to run on a mainframe computer, while the present version is programmed in Continuous Simulation Modelling Program-CSMP (IBM 1975), which is adapted for use on personal computers (Jensen et al. 1987).

Secondly, Dijkstra's version considers digestion and absorption only in the fore-stomach and small intestines, while the present one accounts for processes in the large intestine also. According to Cecava et al. (1990), fibre, starch and feed protein could be digested in the caecum at a rate of 8, 15 and 20%, respectively. Volatile fatty acids (VFA) and ammonia originating from caecal degradation are absorbed and recycled into the gut (Dixon and Nolan 1982). So, the model accounts for digestion in the large intestine, using coefficients from Cecava et al. (1990), and assumes that VFA and ammonia released in the caecum are totally absorbed and incorporated into their respective pools together with those of ruminal origin.

The last difference is related to EPN. To represent the kinetics of EPN in the GIT of ruminants a simple model was developed (Assis et al. 1997). The model contains three pools corresponding to stomach, small intestines and large intestines and uses two sources (secretions and inflow) and exits (absorption and passage) for EPN. It is used as a sub-model in the current nutrient kinetics model.

Model evaluation

Dijkstra's version (ACSL) has been checked against data derived from digestion trials with fistulated cattle fed sugarcane-based diets (Dijkstra et al. 1996). Predicted values for rumen ammonia concentration and for NDF abomasal flow were in good agreement with reported data (Oliveira 1990; Matos 1991). However, NAN flows in the abomasum seemed to be underestimated, probably due to the disregard of EPN additions in the gut sections, which are considered in the current version, i.e. CSMP. The same experimental data used to validate the ACSL version (Oliveira 1990; Matos 1991) were applied to evaluate the CSMP version. Comparisons between both versions with respect to NDF and NAN flows at the duodenum, and VFA and ammonia concentrations in the rumen are shown in Figure 2. In general, the nitrogen section has been improved in the CSMP version due to the EPN inclusion, especially when Oliveira's data are considered (Figure 2c–d). However, the CSMP version slightly underestimates fibre flow and overestimates VFA concentration (Figure 2a–b).

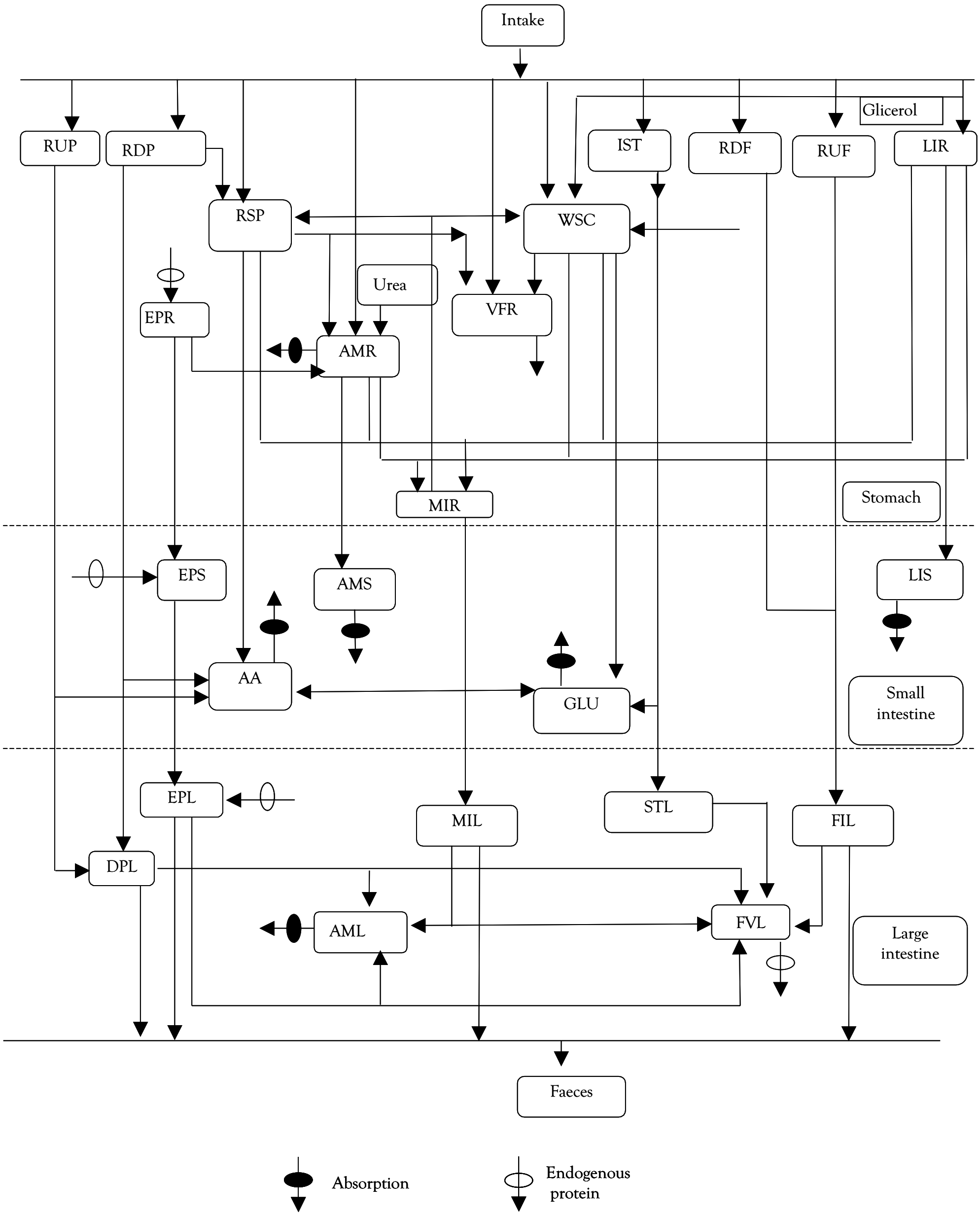
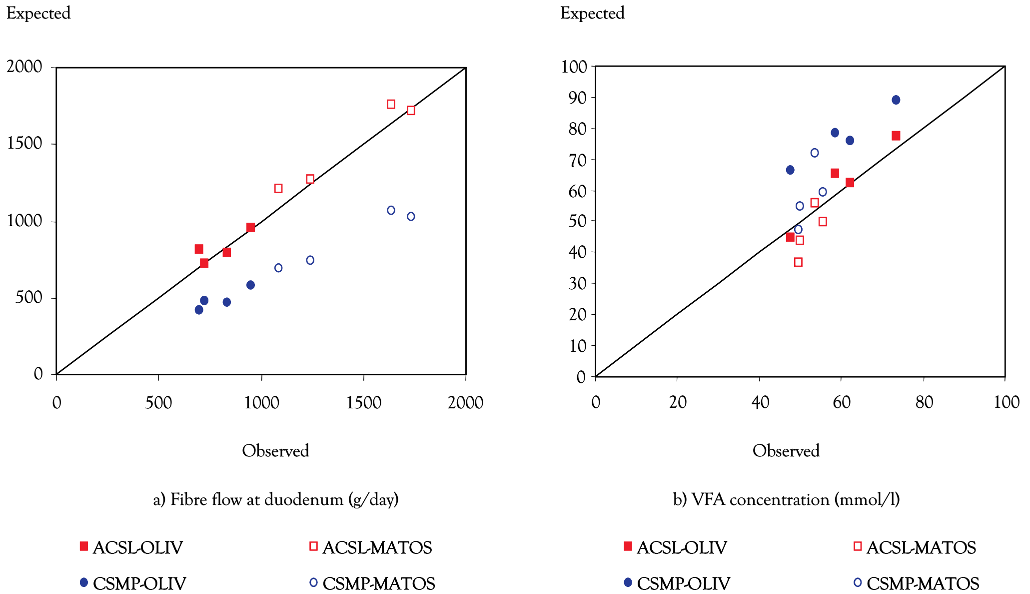
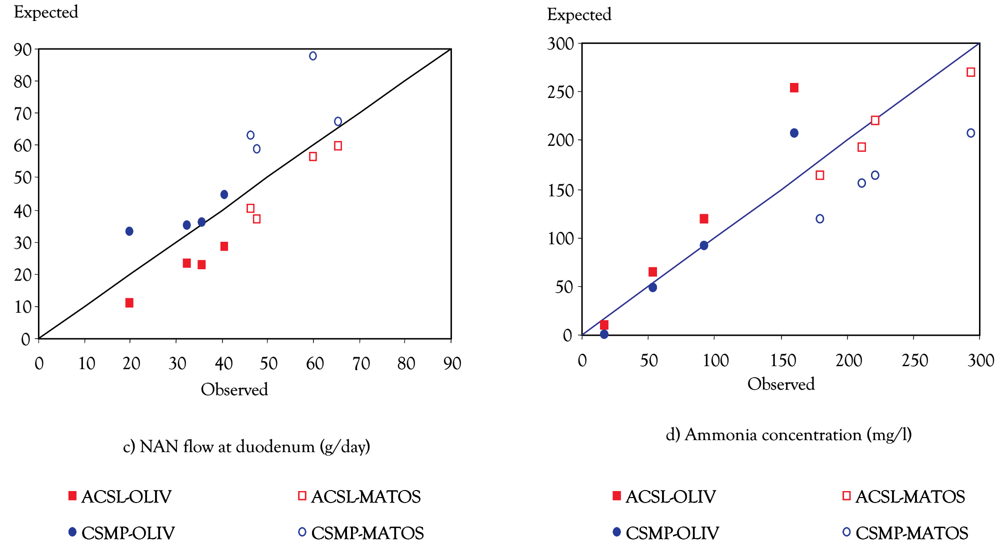


Figure 1. *Representing nutrient kinetics in the gastro-intestinal tract of ruminants.*



a) Fibre flow at duodenum (g/day)

b) VFA concentration (mmol/l)



c) NAN flow at duodenum (g/day)

d) Ammonia concentration (mg/l)

Figure 2. *Comparison between observed values from digestion trials with simulated values from present (CSMP) and previous (ACSL) versions of the model.*

Model application

To verify the model's consistency and its potential use for evaluating alternative feeds for ruminants, simulation trials were carried out with four different supplements for 300 kg dairy heifers eating sugarcane-based diets at 6.0 kg dry matter/head per day. Urea was incorporated into the forage diet at a rate of 200 g/head per day. Supplements used in the test were cottonseed meal, soybean meal, rice meal and maize grain at 1.0 kg/head per day.

Results of these simulations (Table 1) showed that inclusion of cottonseed or soybean meal in the sugarcane-urea diets increased the total amino-acids supply at the small intestine, more than two-fold. This increase was due mainly to dietary protein (five to six times) rather than microbial protein (11%). On the other hand, the same amount of rice meal or maize grain increased total AA at the small intestine by 40%, only, due to by-passed dietary protein and microbial protein. In this case, microbial synthesis was enhanced (14 and 34%, respectively), probably as result of the greater supply of less rumen degradable carbohydrate (starch) in the supplements. Glucose supply increased consistently from 35% with rice meal supplement to 54% with soybean meal. Supplementation with rice meal improved lipids at the small intestine by three times, while soybean meal increased lipids by only 28%. Although supplements have increased supplies of amino-acids and lipids more than 40%, energy increased by 26–30%, only.

Table 1. *Nutrient flow and amino-acids profile at the small intestine of cattle fed 6 kg/day (DM basis) of sugarcane (SC) plus 200 g/day of urea (U) with or without 1 kg/day (DM basis) of cottonseed meal (CM), soybean meal (SM), rice meal (RM) or maize grain (MG).*

Nutrient supply	SC + U	SC + U + CM	SC + U + SM	SC + U + RM	SC + U + MG
Amino acids (g/day)	315.45	677.57	742.49	445.62	438.06
Microbial	230.11	226.3	226.21	231.12	271.28
Endogenous	38.7	45.04	45.04	45.02	44.83
Dietary	73.64	406.23	471.25	169.48	121.96
Glucose (g/day)	354.17	497.2	545.36	477.09	490.01
Lipids (g/day)	48.15	98.95	61.53	148.54	101.56
Energy (MJ/day)	51.55	66.02	66.07	64.76	67.64

This simulation exercise indicates that after correcting AA supply, energy could be the next nutrient limiting animal production on sugarcane-based diets. Furthermore, the supply of energy seems to be limited by glucose, since the energy and glucose response to supplementation followed the same pattern (Table 1).

Conclusion

Consistent results from simulation trials showed that the present model could be a powerful tool to manipulate theoretical nutrient supply for ruminants in the tropics. Also, it could be applied to evaluate the potential use of crop residues for cattle in undernutrition conditions.

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Socio-economic aspects of undernutrition of ruminant livestock

Implications of feed scarcity for gender roles in ruminant livestock production

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Summary

Gender division of labour in ruminant livestock production systems varies across regions according to economic and socio-cultural factors. There is a distinct age and sex division of work in pastoral (nomadic and sedentary) systems. Men are in charge of general herd management and selling of livestock. Women carry out dairy-related activities and manage vulnerable animals (calves, small ruminants, sick, injured and pregnant animals). Children undertake most of the routine work such as herding. In the mixed systems both men and women take part in animal husbandry activities such as harvesting and transporting feed, chaffing of fodder, feeding of animals, milking, cleaning of sheds and sale of milk. Their degrees of involvement in each activity vary from place to place. Processing of milk is solely women's job. Children of both sexes tether and herd animals. Like in animal husbandry activities, crop cultivation tasks are shared among household members and also vary across regions.

Feed scarcity increase work burden of all household members, but more for women and children in many situations. Feed scarcity reduces livestock, crop and non-farm productivity. It reduces availability and access to food, via decreased food supply and incomes and hence reduces food and nutrition security and consequently human welfare.

Introduction

Ruminant livestock is an integral part of most agricultural production systems of developing countries. They are important in maintaining the livelihood viability of their keepers by providing food, traction power, manure, raw material, cash, security, social and cultural identity, medium of exchange and means of savings and investments. The demand for ruminant livestock is increasing with rising population, urbanisation and incomes. Several constraints, however, limit livestock productivity growth. These include inadequate and poor quality feeds/fodder, animal health problems, unavailability and high cost of improved breeds, and poor livestock management. The inability to adequately (quantitatively and qualitatively) feed animals is a critical problem in smallholder ruminant livestock production systems in the tropics.

Gender roles in agricultural production became an important subject of inquiry after Boserup (1970) called into question if women and men benefited equally from development. Gender is broadly defined to include socially prescribed responsibilities and tasks according to age and sex. Although gender refers to men, women and children, particular attention is normally given to women, because in some cases, they undertake major responsibilities in agricultural production—especially for subsistence, in addition to performing household chores and reproductive activities, most of which go unrecognised in employment records.

This paper examines the implications of feed scarcity for gender roles in ruminant livestock production in the tropics on the basis of available literature, which is scanty. The smallholder ruminant livestock production systems considered are nomadic, agro-pastoral and mixed crop–livestock farming. The paper begins with a brief discussion of gender division of labour in these systems.

Gender division of labour in nomadic and agropastoral systems

Nomadic and agro-pastoralists have distinct age and sex division of labour and responsibilities. Men are in charge of general herd management. This responsibility requires constant attendance at markets and other gathering places to obtain information on range conditions, water availability and incidences of diseases. They direct the herders and guarantee that animals are well fed and watered. Men also take care of the dips, carry out most of the dipping, and supervise spraying of animals. They inspect animals in the evening to ensure that none is missing, or sick and if any is about to give birth. Men buy and administer veterinary drugs, perform minor veterinary procedures and castrations, sell and buy animals after consulting other family members.

Women are primarily responsible for dairy-related activities. They milk cows, process milk into butter and cheese, and market surplus milk and dairy products. Women take care of stocks requiring particular attention—such as pregnant cows, new born calves, injured and sick animals that are normally kept near the camp. They ensure that these animals are well fed and watered. Women play significant roles in animal disease control. Their close contacts with the cows via milking enable early spotting of diseases. An abrupt drop in the milk yield is an indication of ill health (Bruggeman 1994).

Children carry out most of the animal husbandry routine work; they do all the herding and much of the work around the homestead. Compared to boys, girls herd mostly small stocks. Herding small stocks and calves permit girls to return to the homestead on time to help in food preparation and other domestic chores. Children also assist in milking and watering of animals.

The gender division of labour in animal husbandry described above is fairly common among the Maasai in Kenya (Grandin et al. 1991), the Boranas of Ethiopia (Coppock 1994), the Baggara and Fulani nomads of South Darfur in Sudan (Kerven 1987), the agro-pastoralists in central Nigeria (Waters-Bayer 1988) and the Beja of Sudan (Morton 1990). Gender division of labour is not very strict in these systems. When need arise, men milk the cows. In central Nigeria (Waters-Bayer 1988) and the Beja of Sudan (Morton 1990), for example, it is mostly the men and the boys that milk the cows and allocate the milk to different uses.

In addition to animal husbandry, agro-pastoralists cultivate crops. All household members contribute labour to cropping. In the agro-pastoral system in central Nigeria, for example, the plots are managed by men, who with the help of hired labour and older sons undertake crop cultivation activities (Water-Bayers 1988). Women help in planting, fertiliser application and weeding. Grain harvesting is undertaken by all family members but women and girls carry most of the harvest home. Women do post-harvest work, though men construct granaries and help in crop storage. Women also keep small kitchen gardens with various vegetables, condiments, shrubs and trees bearing edible leaves and fruits. They work on their gardens with the help of their children and hired farm boys.

In addition to agricultural production, women are responsible for the daily and time consuming tasks of childcare, food preparation, and water and fuel collection. Nomadic pastoral women build and maintain homes. This necessitates dismantling the houses, loading them on the donkey or oxen for transportation, and rebuilding them at the next camp.

Gender division of labour in mixed crop–livestock systems

Gender division of labour varies from region to region in mixed crop–livestock production systems, based on culture, religion and socio-economic variables. A large number of animal production related tasks like harvesting and transporting feed (green grasses/weeds, fodder, forages etc.), chaffing of fodder, feeding and milking of animals, cleaning of cattle sheds and sale of milk products through formal and informal channels are done by both men and women, in varying degrees in different regions. Milk processing is primarily the work of women. Children of both sexes graze animals. Men make decisions about breeding of animals and marketing of large ruminants.

For example, women's labour contribution to ruminant livestock management is highest in their households, in the Coastal province of Kenya (Mullins et al. 1996), in the Ghusel village of Nepal (Thomas-Slayter and Bhatt 1994), in the Karnal and Nadia districts of Haryana and West Bengal (Dhaka et al. 1994). In the high castes and rich families in Ahmedabad and Udaipur districts of India, most of the animal husbandry tasks are undertaken by either men or hired labour (Rangneke et al. 1993). Children provided most of the animal husbandry labour in Holetta, Ethiopia (Shapiro et al. 1998)

In intensifying mixed farming, the traditional gender responsibilities in animal husbandry are subject to negotiation and change over time. Technological change and market-oriented smallholder dairying, for example, affect the basis of gender division of labour. It has been reported that where intensified dairying is associated with hand feeding (stall-feeding), the extra labour burden disproportionately falls on women (Chavangi 1983; Whalen 1984; Dhaka et al. 1994; Muylwijk 1994; Thomas-Slayter and Bhatt 1994; Mullins et al. 1996).

In addition to raising ruminant livestock, crop cultivation is an integral part of the farming system, and in most cases, the most important for farmers' livelihood. Gender division of labour for crop production varies from one place to another. Women in many places in sub-Saharan Africa (SSA) contribute most of the labour to subsistent crop production than any other household member, except in Ethiopia, where men do most of the farm work and women and children only assist. In mixed systems, women with the assistance of girls, also undertake daily chores such as cooking, washing, cleaning, child rearing, agricultural work, tending kitchen gardens etc.

Gender effects of feed scarcity in nomadic pastoral system

The possible gender effects of feed scarcity in nomadic pastoral system are illustrated in Figure 1.

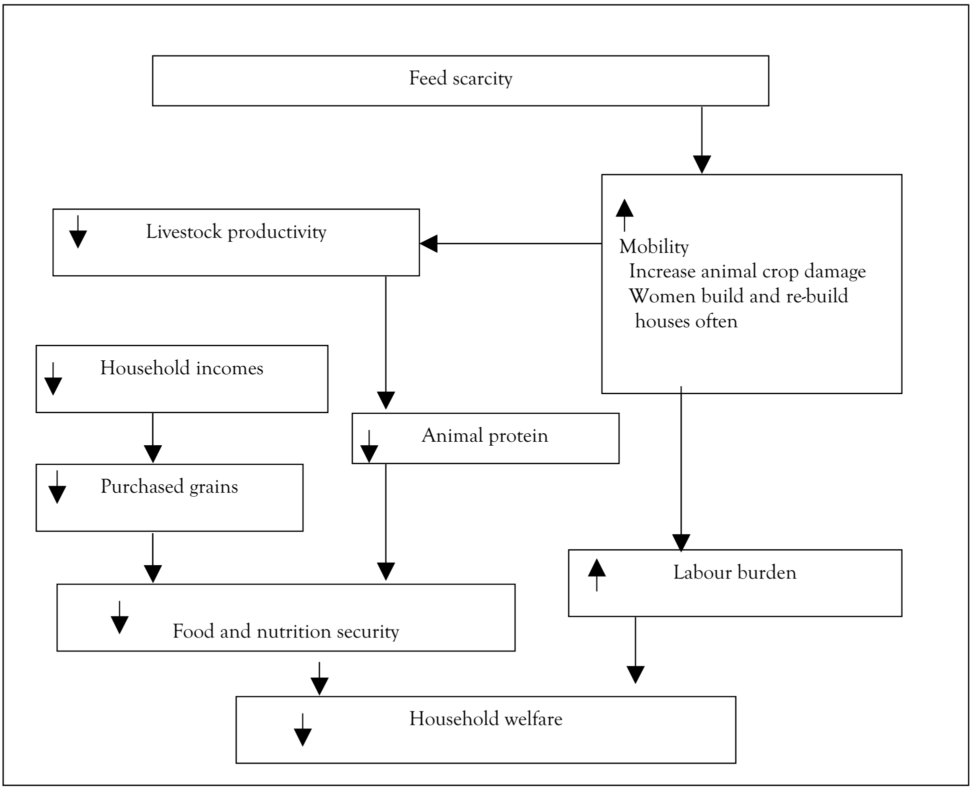

Figure 1. *Gender effects of feed scarcity in nomadic pastoral system.*

- Feed scarcity increases mobility of household members and livestock. Herders, mostly boys under the guidance of their fathers frequently travel long distances with animals in search of feed and water. Recurrent movements from place to place increase risk of crop damage by animals, and increase women's workload, as they are responsible for building and re-building of camps more often.
- The effect of feed scarcity and high mobility is diminished nutrient intake. This lowers livestock productivity, particularly milk offtake.
- In contrast to the feed abundant situation where human diet is dominated by milk, meat and in some cases blood, the diet under feed scarcity may be composed mostly of grains. Cereal menus in comparison with milk-based diets require more resources to prepare. Women, with the help of girls spend more time fetching fuel wood, water and cooking food.
- Assets loss (reduction in herd inventory) due to feed scarcity is high. Most of the loss results from starvation and a smaller proportion due to sale and slaughter of animals.
- Another effect of feed scarcity is reduced pastoral terms of trade, i.e. the price of cereals and other consumer goods increase due to high demand, while livestock prices decrease, as a result of increased supply. The strategy of most pastoral families during initial feed shortage periods is to sell the same number of animals as in normal times, but to use more of the income to purchase grains. Increased livestock sales occur in the later stages when there is no anticipation for improvements in feed availability.
- Decrease in milk production and consumption, reduction in incomes from sale of animals and the decreased ability of households to purchase more cereal reduce their food and nutrition security. Increased workload of all household members and increased food and nutrition insecurity reduces human welfare.

Gender effects of feed scarcity in agro-pastoral system

The possible gender effects of feed scarcity in agro-pastoral systems are illustrated in Figure 2.

- Agro-pastoral systems develop from nomadic system when livestock keepers settle around permanent sources of water with crop cultivation supplementing livestock production (Camoens 1985). Feed shortage is one of the reasons that induce settlement.
- With feed shortage, men and boys spend more time on herding. In such situations, women and children may also assist in herding. This increases competition in labour demand between herding and cropping.
- As in nomadic pastoral system, feed scarcity reduces livestock productivity and may force farmers to further reduce their herd sizes.
- Lower livestock productivity and increased competition on household members' time between herding and cropping, may result in lower crop productivity as well. Reduced crops and animal output diminishes households' food supply and incomes, and hence their capacity to achieve food and nutrition security.

- The overall effect of feed scarcity in agro-pastoral system is decreased livestock productivity, reduced income from sale of livestock and livestock products, reduced availability and access to food, increased labour burden of all household members, and reduced food and nutrition security and human welfare.

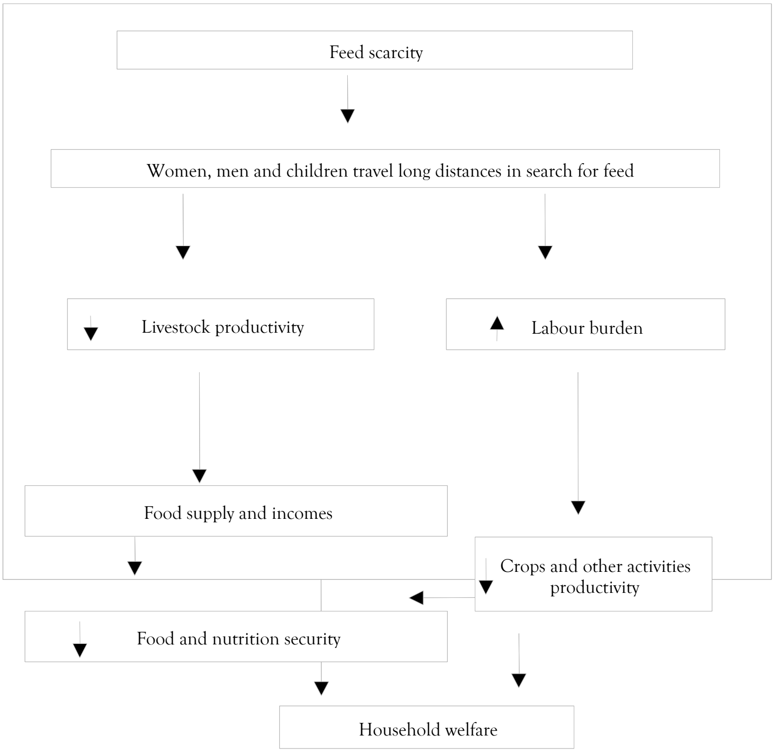

Figure 2. *Gender effects of feed scarcity in agro-pastoral system.*

Gender effects of feed scarcity in mixed system

The possible gender effects of feed scarcity in mixed farming systems are illustrated in Figure 3.

- Crop production for both subsistence and cash generation is the main activity of mixed farming system, with livestock playing a supportive role. The exception is in intensified systems, where livestock production generates more income than crop production.
- The immediate feed scarcity effect in mixed systems is increased long distance travel by men, women or children according to gender division of labour and region in search of feed, whose quality is low in most cases. Poor feed reduces livestock productivity.
- Increased animal husbandry labour input may reduce time spent on crops and other activities, if the labour supplies of members responsible for such tasks are inelastic.

Agricultural production and incomes may therefore reduce, having a negative impact on food and nutrition security.

- Reduction in food and nutrition security in addition to increased labour burden, reduce household welfare

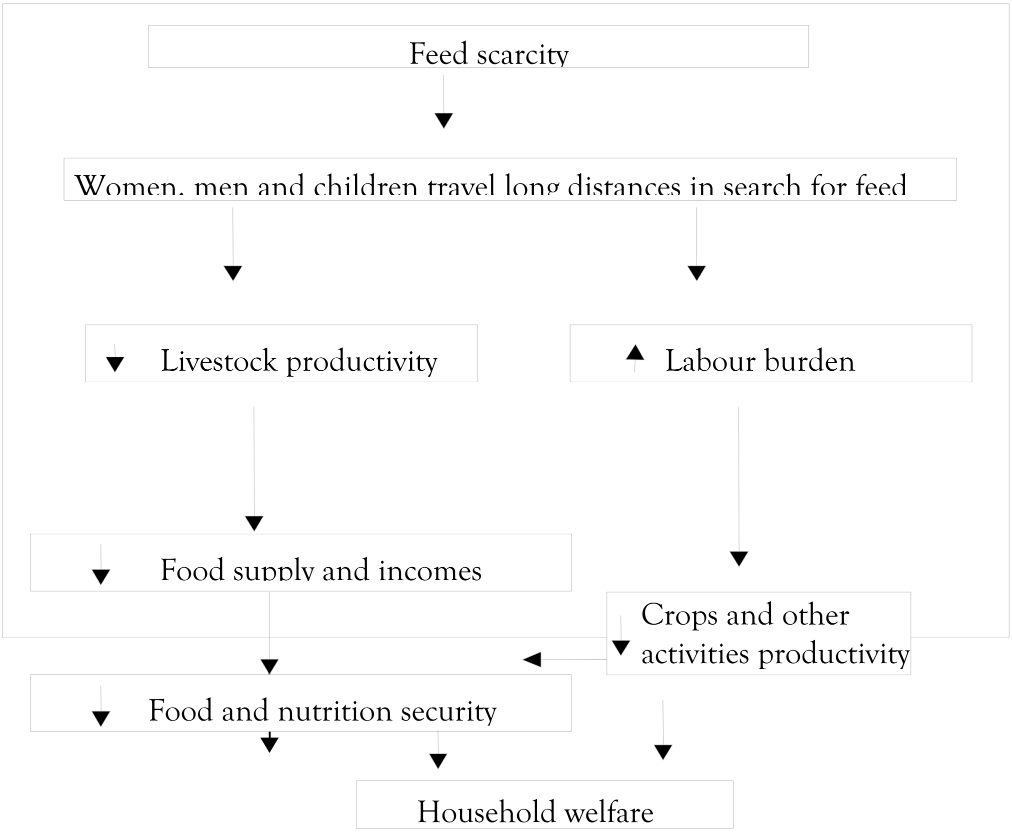

Figure 3. *Gender effects of feed scarcity in mixed systems.*

Conclusion

A limited amount of available literature suggests that feed scarcity increases work burden of all household members and reduces agricultural productivity. This lowers food availability and incomes and hence households' ability to achieve food and nutrition security. Individual member's increased labour burden further reduces their overall human welfare. These relationships need to be empirically established by undertaking appropriate research in different parts of the world and in different production systems.

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