HARRY STOBBS MEMORIAL LECTURE FOR 1987*

THE FUTURE FOR THE GRAZING HERBIVORE

R. J. JONES

CSIRO Davies Laboratory, Private Mail Bag, P.O. Aitkenvale, Queensland 4814, Australia.

*Talk delivered in Brisbane on July 7, 1987 at the University of Queensland in conjunction with the Tropical Grassland Society of Australia, Australian Society of Animal Production, Australian Institute of Agricultural Science and the Second International Symposium on the Nutrition of Herbivores.

INTRODUCTION

It is a great honour to be asked to deliver the 1987 Harry Stobbs Memorial Lecture.

I first met Harry Stobbs in Africa where we both had worked with the then British Colonial Service—Harry in Uganda and I in Kenya as Agricultural Officers. Harry made a tremendous impact on animal experimentation in the work he did at Serere and highlighted the value of sown pastures for increasing animal production.

He came to Australia in 1969, bringing with him valuable experience from Africa, infectious enthusiasm, and boundless energy—brimful of ideas he wanted to try out! For a number of years we shared the task of showing visitors around the experiments at the Pasture Research Station at Samford—an interruption in the research work which Harry may have been irritated about on occasions but which never showed in his lucid presentation of results to farmers and scientists alike. One would not have wished for a more stimulating and challenging colleague with whom to share ideas or discuss results.

Tonight I have the challenging task of looking into the future. Unfortunately I was unable to place a requisition for a crystal ball since funding for speculative research was (is) unavailable! My aim is to assess, in broad terms, the success to date of the grazing herbivores (in particular the domestic herbivores) and the reasons for this success, examine some of the factors which might lead to a change in this situation, consider the likely impact of research and the resulting new technologies in the future for both developed and developing countries, and finally to highlight the potential for land degradation resulting from increased numbers of domestic herbivores.

THE SUCCESS OF THE GRAZING HERBIVORE

Herbivores are found in habitats as diverse as deserts, arctic tundras and warm, mesic environments. Domesticated or semi-domesticated, they have a similar range of adaptability to that of man, so that grazing herbivores are a feature of most societies.

Undoubtedly, their success can be attributed to an ability to utilise long-chain structural carbohydrates in the vegetation of grasslands and woodlands. Animals themselves do not produce enzymes capable of attacking these carbohydrates—it is their symbiosis with micro-organisms, capable of fermenting these food sources inside the animal in compartments of the gut designed for the purpose (Langer 1984), which enables them to utilize the roughages effectively. Of the many adaptations of the gut found in herbivores (Hoppe 1984) the rumen, characteristic of ruminants, and the enlarged colon and caecum, characteristic of hind gut fermenters, are the adaptations found in domestic herbivores.

The products of fermentation by the gut microbes produce volatile fatty acids (VFA) as a major energy source. The ability to use fibrous feeds through this amazing symbiosis with microbes enables the grazing herbivores to survive the often extreme variation in quality of the available feed through dry or cold seasons. Their survival has, in turn, aided the survival of man who, in former times, and even today in pastoral communities, depends very largely on the grazing herbivore for food, clothing, transport and even fuel.

It has been the ability of domestic herbivores to provide man with a variety of products and services from the natural grazings which has led to their significance in all continents of the world.

PRESENT STATUS

Over the last 300 years, European man has taken his herbivores to populate N. America, S. America, Southern Africa, Australia and New Zealand. In these new environments these animals were able to utilise the native grasses to provide food and essential services to the pioneers in their development of these new territories (Joubert 1984). The fact that these herbivores did not compete directly with man for food, and that they had a well developed intra-specific social life, enabled flock and herd management systems to be devised which were simple and effective (Williams 1981). The ability of the ruminants to produce nutritious food—(meat and milk), hides, skins, hair, wool and dung for supporting crops—together with draught power for cultivating land for crops, not only provided for sustenance directly but was also the basis for home and village industries (Williams 1981).

As Williams (1981) points out, all domesticated herbivores were multi-purpose animals. In the West we have tended to forget this—not so the developing countries where the multi-purpose role of herbivores is still of utmost importance.

The differing roles of herbivores in the developed and developing countries has been emphasised by McDowell (1980) who points out that, although the vast majority of animals are eventually consumed as meat and their milk utilised in homes, the perceptions of priorities associated with livestock are different (see Table 1).

TABLE 1

Priorities for livestock ownership in developing and developed countries (McDowall 1980)

Developing Countries	Developed Countries
Reduce risks from cropping	Derive income from:
Accumulate capital	MEAT MILK FIBRE
Obtain services—eg. traction, transport, fuel, fertilizer	Diversify farm operations and income
Satisfy cultural needs	Extend use of non-arable lands
Insure status or prestige	Prestige
Provide food	Generate Capital
Generate income	

Of course the differences are not as clearcut as indicated, since, as countries develop, there will arise livestock practices similar to those in developed countries, eg, dairy farms around cities in developing countries. Nevertheless, it is important to note the multiplicity of roles for herbivores in the developing countries if we are to predict what their future might be. It has been estimated that 23 million pastoral nomads in Africa, the Middle East and central Asia control over 120 million livestock units grazing in areas with annual rainfall generally < 600 mm (McDowell 1980).

The major non-food commodities produced by grazing herbivores are:

Fibre

Wool is the main fibre in world commerce, valued at $A4 billion annually from 1.4 million tonnes of wool (BAE 1986). However, developing countries produce little wool. Long hair for yarn and carpets is however produced and the llama and alpaca produce the finest grade of wool. Some 30% of the world supplies of mohair are from developing countries. Food resources for the total output of fibre from grazing herbivores comes almost entirely from land too arid, steep or poor for cropping.

Skins and Hides

This trade is worth U.S.$3.5 billion annually. As an export commodity it ranks in the first 10 for 30% of developing countries. However, although providing 40% of the 6 million tonnes of hides/annum, the developing countries only receive 20% of this total value (Barat 1975). Somewhat surprisingly, the hides and skins from developed milking breeds or meat breeds of cattle and sheep are not the highest quality. The Red Sokoto goat from W. Africa produces the finest skins.

Power

There are estimated to be 400 million draught animals in the world (Lowe 1986) and these provide 75–90% of power used in agriculture (McDowell 1980). The advent of steam and internal combustion engines caused one of the greatest changes in the distribution of grazing herbivores in the developed countries when they replaced horses and oxen as the main sources of power for agriculture and transport. However, this dramatic change has not occurred in most developing countries. In India, 70 million bullocks, 8 million buffalo, 1 million camels and 1 million horses provide power for agriculture and allied industries (McDowell 1980). The 40 million h.p. they could generate approximates to 30,000MW of electrical power (Jana and Chandhuri 1985). It is estimated that their replacement by machines would cost > U.S. $1 billion/annum in fuel alone at 1980 prices. In view of likely increases in fuel costs, dependence on animal power will increase again in many developing countries. In China, the dependence on equine power for transport of materials is staggering, with some 71 million horses in addition to buffalo and oxen.

Fuel

It is estimated that 300 million tonnes of manure are used for fuel in developing countries. Cow dung has approximately 4.6K cal/g. India uses some 60–80 m Mt annually of dried buffalo dung (worth > $3 billion annually in coal equivalents). It is also vitally important in Ethiopia where wood resources are low. In these countries, 60% and 30% of the cash income of some of the poorer families is derived from the sale of dung (McDowell 1980).

The value of dung has resulted in poor acceptance of methane (biogas) plants using dung. Thus in India only 20,000 and in S. Korea 29,000 plants have been established. Although the effluent is useful as a fertilizer the material is useless for making dung cakes for use as fuel.

Fertilizer

Animal wastes are important in maintaining soil fertility in developing countries. Forty percent of farmers in the world depend on wastes for the nutrient needs of their crops. In Africa pastoral herders are paid by cultivators to herd cattle in their fields to enhance soil fertility.

Capital reserve

Herbivores are often seen as readily cashable assets in time of need, e.g., hospital expenses, school fees, emergency feed purchases in droughts, seed purchases and fertilizer purchases. This vital role is often as important as their value for food and the provision of power.

Cultural

In recreation, religious festivals, sacrifices, social gatherings and bride prices, grazing animals feature in many societies. The running of the Melbourne Cup in Australia is a classic example of herbivores providing a focal point for recreation, social intercourse and almost religious fervour!

In view of man's close association with, and dependence on, the grazing herbivores, it is to be expected that domestic herbivores have increased in number as the human population has increased. The world population of domestic herbivores in developed and developing countries is shown in Table 2.

The developing countries have populations of cattle, buffalo, camels, goats and equines greatly exceeding those of the developed countries. Only for sheep are the numbers comparable, doubtless due to the large numbers of wooled sheep in Australia, New Zealand and S. Africa. The dominance of cattle is apparent, particularly if comparisons are made on the basis of weight or food consuming capacity (Table 2). On this basis, the results have changed little from the statistics for 1978 (Henzell 1983).

TABLE 2

World livestock numbers according to species for developing and developed countries, and their percentage contribution to total numbers and to total animal units (A.U.)[1]
(Data from FAO 1985)

Species	Developing No. (10^6)	Developed No. (10^6)	Total	% (Nos)	% (A.U.)
Cattle	844.4	428.1	1,272.5	40.6	71.0
Buffaloes	125.4	0.7	126.1	4.0	8.8
Camels	16.9	0.3	17.2	0.5	1.3
Sheep	595.3	544.2	1,139.5	36.4	7.9
Goats	432.7	26.8	459.5	14.7	3.2
Equines	94.7	23.3	119.0	3.0	7.8
TOTAL			3,133.9	100.0	100.0

[1] Animal unit = 1.1 for camels, 1.0 buffalo, 0.8 cattle, horses and mules and asses, 0.1 sheep and goats.

Australia has some 139 million sheep, 19 million beef cattle and 2.8 million dairy cattle (Australian Bureau of Statistics 1985). The production of wool, meat and milk from these grazing herbivores has contributed greatly to the development of the country. Even though the relative contribution of the rural industry to the exports has declined with time, the importance of the livestock sector is still large (Table 3).

TABLE 3

Exports of selected rural commodities from Australia in 1985/86
(ABARE 1988)

	1985/86 $M
Crops	5285
Livestock Products	
Wool	3052
Beef and Veal	1292
Mutton and Lamb	216
Canned Meat	46
Live Sheep	169
Dairy Products	437
Total Livestock Products	5230
Total Rural Exports	11660
Gross Rural Production	15515
Livestock products as % of Total Rural Exports	44.8
Livestock products as % of Total Gross Rural Production	33.7

THE FUTURE

Wild Herbivores

Wild herbivores have diminished with time as both the human and domesticated grazing herbivore populations have increased. This is inevitable as competition for the grazing resources increases. Some herbivores have been lost forever, eg., the blue antelope (*Ozanna leucophaea*) and the quagga (*Equis quagga*) from S. Africa, whilst others that were on the verge of extinction in Africa have been saved by conservation efforts (Joubert 1984). The demise of the bison in North America is a classic case of a grazing herbivore diminishing with the advent of European man and his introduced herbivores.

In Kenya, wildlife outnumbered domestic livestock in only two districts out of 38 surveyed. In the districts with high human populations no data on wildlife were available, but it can be assumed that numbers would have been small (Peden 1987). This is understandable as humans and wildlife don't readily mix.

In Australia, modification of some habitats has led to the extinction of several native herbivores including the eastern hare wallaby (*Lagorhestes leporides*), crescent nailtail wallaby (*Onychogalea lunata*), desert bandicoot (*Perameles eremiania*) and pig footed bandicoot (*Chaeropus ecaudatus*) (Hume 1987). In contrast to this, some large marsupials have increased with provision of water and the modification of the habitat for introduced herbivores to provide the short grasses favoured by kangaroos and wallabies (Hume 1987).

Introduced herbivores may not only compete with native herbivores but also with other introduced herbivores deemed to be of greater value—the spread of the European rabbit in Australia and the devastating effect on the vegetation resulted in a marked reduction in sheep carrying capacity of the Western Division of New South Wales from 7.3 million in 1891 to 1.5 million in 1911. The devastating effects on the soil and vegetation were such that the earlier sheep numbers attained in periods of good rainfall, have never been attained since (Frith 1970). Although myxomatosis effectively controlled the rabbit plague in the 1950s to 1970s there is a resurgence of this pest as the deaths due to myxomatosis have declined (Hume 1987). Continuing research will be required to develop control methods to ensure that this grazing herbivore does not assume its former population levels.

In the future many of the wild herbivores will only be seen in designated National Parks, zoos and privately owned game ranches.

Farming wild herbivores

For some considerable time, the potential of wild herbivores has been proposed, particularly for Africa (Talbot *et al.* 1965; Reul 1979). There is little doubt that many of the game species have growth rates equal, or superior, to the domestic species under range conditions and have a high yield of lean meat. They also have superior disease and pest resistance, although all appear to be susceptible to foot and mouth disease and rinderpest. Their water intakes are also lower than those of domestic stock. Temperament and difficulties in herding exclude many species as candidates for domestication. Of the larger species, the oryx and the eland appear to offer most promise (King and Heath 1975; Reul 1979). However, the eland is not well adapted to the hot semi-arid areas, particularly if restricted to a limited range area (King and Heath 1975).

An unusual tropical herbivore—the Capybara (*Hydrochaerus capybara*)—is a rodent indigenous to the wetlands of S. America. Credited with a six-fold increase in reproductive efficiency compared with cattle and a turn off rate of 40% compared with 6 to 11% for cattle, profitability in the ecosystems to which it is adapted may be three times higher than for cattle (Gonzalez and Parra 1973). As it is a carrier of diseases of horses and cattle, it is not favoured by some ranchers. As with most other wild species, problems of management and suitable market outlets could limit large scale production.

Currently, the use of deer has gained popularity in New Zealand, and more recently still in Australia. However, contrary to what may have once been thought, they are farmed intensively rather than extensively in N.Z. and under these circumstances are highly productive (Woodford 1987). With nearly 0.5 million deer (mainly red deer), N.Z. is set to capture a specialist market for low energy venison (Drew and Bigham 1987).

Semi-domesticated and wild herbivores are adapted to the tundra and extreme northern environments. The reindeer and the caribou together number towards 4 million, and are found in much larger numbers than the musk deer, moose, bison and wild sheep (Hudson and Bunnell 1981).

In Australia, farming of kangaroos and wallabies (rather than growing sheep and cattle) has been suggested from time to time. Whilst there may be biological reasons for thinking they would provide more protein at less cost, handling problems, marketing problems and public opinion would be formidable deterrents (Shepherd 1983). As a pest of agriculture, kangaroos are harvested commercially for pet meat, export meat and for their skins. In the period 1980–1984 the number of skins exported overseas from New South Wales varied from 0.5 m to 1.2 m/yr, not all shot in New South Wales. Over the same period the export of kangaroo meat from Australia ranged from about 600 t to 1,580 t/yr with a value of A$0.7 m to A$3.2 m (Morris and Young 1987). The tonnage of kangaroo meat used in Australia may have exceeded the amount exported by a factor of 7 or more.

Although there is scope for the use of wild herbivores for food production, my overall impression is that management problems will limit more intensive use of such animals so that their potential impact on increasing food production from marginal habitats will be small, though perhaps locally important. With the small base population, even the most optimistic predictions for growth will mean little impact in the foreseeable future. However, wild grazing herbivores will continue to be earners of foreign exchange from tourism and hunting, particularly for countries in Africa.

Domesticated herbivores

The characteristics which enable grazing herbivores to play such an important role in the past are likely to be those characteristics which will be needed in the future if the growing human population is to be adequately fed and clothed. With increasing use of the better watered and higher fertility land for cropping (and also urban development), grazing herbivores are being carried on the drier, steeper or lower fertility areas. In many instances this is the only way these lands can be used to provide food—although large areas are used for forestry in both semi-arid and humid areas.

FACTORS INFLUENCING THE FUTURE FOR THE GRAZING HERBIVORE

Population increase

The human population has doubled since the end of World War II to reach 5 billion. This is expected to increase to 8 billion by 2022 (UNFPA 1987). In some countries, the growth rate has been truly staggering. When I left Kenya in 1960, the population was about 7 million—today it is 20 million with an estimated growth to 40 million by 2005. The implications for a dry country like Kenya are frightening. For the last two decades, world population growth has been linear, with an additional 78 million people to feed each year with the greatest increases in the developing countries (Fig. 1). If this trend continues then the world will need all the food it can produce—including food of animal origin. If the per caput consumption of meat and milk is to remain constant, then to keep up with population growth, animal production will need to increase by 60% by the year 2022.

Increase in living standards

Although the recent droughts in Africa have highlighted the desperate poverty of many peoples in the world, the general trend has been for incomes to increase for the majority of people in both the developed and developing countries. Associated with an increase in purchasing power has been a definite increase in the purchase of animal products. This trend is true when comparing different countries (Fig. 2) or when comparing various income groups within a country. Even in India, with taboos against eating cow meat and with an apparent wastage of 29 million cow carcasses annually, meat consumption is increasing each year (Jul and Padda 1984).

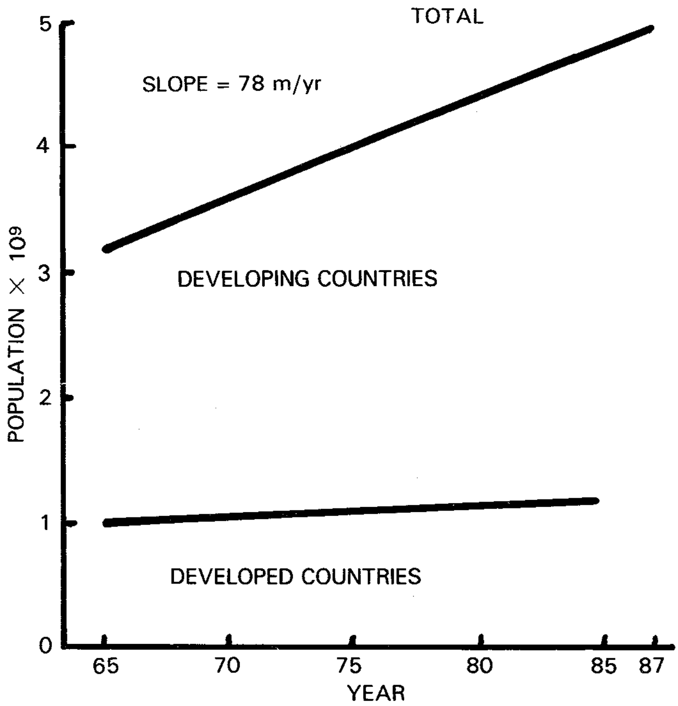

FIGURE 1
World population trends for developed and developing countries (FAO Statistics).

The combination of a rapidly growing world population having a desire to increase animal protein in their diet must lead to a very strong demand for food products from the livestock sector—especially in the developing countries where population growth is more rapid. This combination of factors has led to the expectation that demand for livestock products will increase by about 4.5 percent per annum (Hrabovszky 1981). Approximately half of this increase will be due to a growing population and the remainder to higher per caput incomes. For a number of reasons, most of the demand will have to be met by increased pig and poulty production (Hill 1972), but this assumes that there will be surplus grains for livestock production. Even so, the increase in production required from grazing herbivores to meet the likely future demand is great. To meet the targets proposed by the FAO study "Agriculture toward 2000", increases in both numbers of cattle, buffalo, goats and sheep and in production per head is envisaged (Hrabovszky 1981). For 90 developing countries, the levels of production in 1980 and the target for 2000 are shown in Table 4.

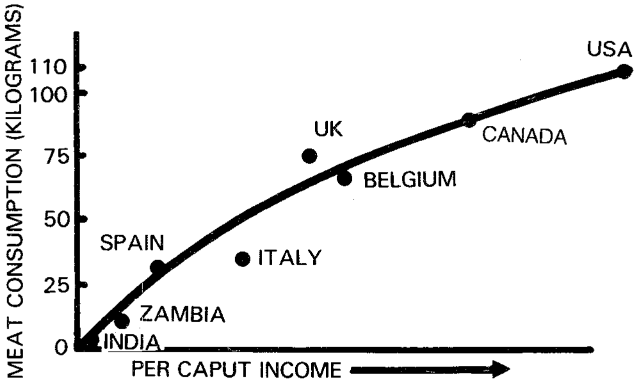

FIGURE 2
The relationship between income and meat consumption (Hill 1972).

TABLE 4
FAO targets for animal production to the year 2000 (Hrabovszky 1981)

	Year		% increase
	1980	2000	
No. Cattle and Buffalo for meat (m)	852	1238	45
Production (mt)	12583	28668	128
No. Cattle and Buffalo for milk (m)	132.4	221.1	67
Production (mt)	84.4	175.1	107
No. Sheep and Goats for meat (m)	0.79	1.17	48
Production (mt)	3.04	6.21	104

A noteworthy feature of the forecasts is the very large increase in production per animal from the herbivore contribution in addition to an increase in their numbers. If this can be achieved, it will reduce the large gap between the productivity of animals in the developed and developing countries as shown in Table 5 (Henzell 1983).

It may well be questioned whether an increase in production per animal can indeed be combined with an increase in animal numbers. Past evidence in the developing countries suggests that this may be difficult to achieve. A repeated theme in discussions concerning animal production is the failure to increase production per animal in spite of inputs of veterinary care and improved practices. This contrasts markedly with the increased yields of cereals/ha which have accompanied the

TABLE 5
Productivities of domestic herbivores (after Henzell 1983)

	Developing Countries	Developed Countries
Domestic Herbivores (m)	953	425
Beef and Buffalo meat (kg/a.u/yr)	20	96
Sheep and goat meat (kg/a.u/yr)	40	65
Milk (kg/hd/yr)	666	3085

World population of domestic herbivores = 2.8 billion.
a.u. = animal unit.

expanding acreage. Increases in animal numbers, rather than in individual animal performance, have been responsible for the increased output of animal products in most developing countries. Is there reason to believe that the anticipated gains per animal can be achieved? Unless the livestock are purely to be utilized for sale of products, then the incentive to obtain higher gains per animal may not be there, particularly if achievement of high yields/animal is associated with greater risk—say, with crossbred or purebred introduced animals—or with higher costs, such as the purchase of concentrates.

For grazing herbivores, the relation between production per animal and production per hectare of the grazing resource (Fig. 3) means that potential gain per animal can never be achieved if maximum production per ha is the goal. Animal geneticists and animal nutritionists cannot expect to see their anticipated potentials expressed in the grazing situation if the objective is to maximise output per ha.

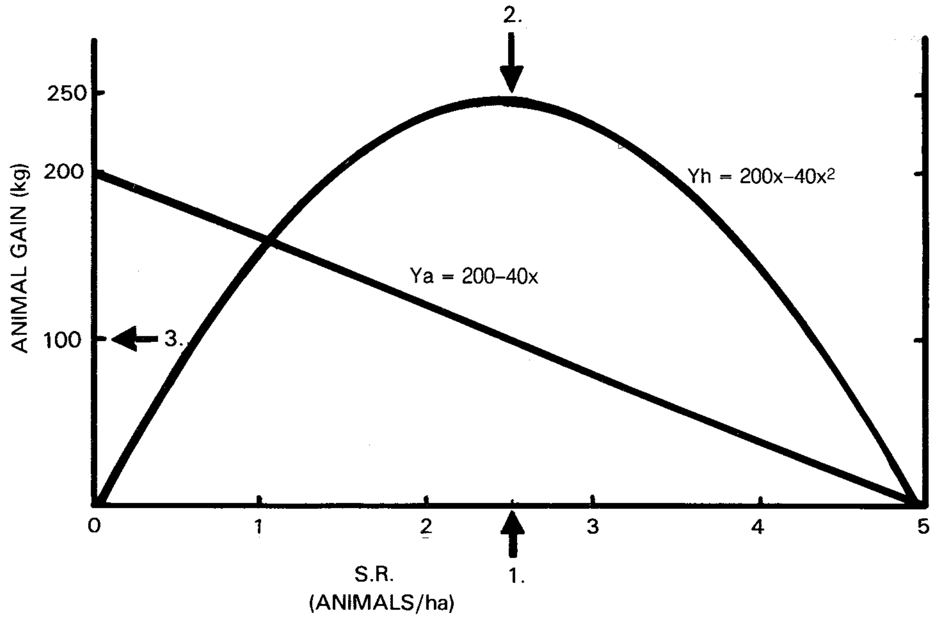

FIGURE 3
The relation between gain per animal (Ya) and gain per hectare (Yh) in response to increasing stocking rate (after Jones and Sandland 1974). Arrows indicate:
1. stocking rate for maximum gain/ha.
2. maximum gain/ha.
3. gain/animal at the stocking rate for maximum gain/ha.

However, if the pasture type is changed and the intercept (a) of the relation between gain/animal and SR is increased, then the gain/animal at SR for maximum gain/ha will also be increased, since the gain per animal at the SR for maximum gain is a/2 if the relation is linear as depicted in Figure 3 (Jones and Sandland 1974). If, in the changed pasture situation, the intercept remains the same, but the slope (b) is changed, then gain/animal at the SR for maximum gain remains the same, but the SR for maximum gain is higher.

In view of these responses, can we conclude that the absence of an increase in productivity per animal measured over time is due to a change in the 'b' value in the SR relationship? In other words, has increased SR led to species composition changes in the pasture which enable it to tolerate increased SR without reducing animal performance? This may be worth thinking about. We may well be experiencing this sort of change in pastures in Queensland where *Bothriochloa pertusa* is replacing *Heteropogon contortus* with increased stocking rate. Of course, at any fixed stocking rate, increase in the 'a' values, or a decrease in the 'b' values will lead to increased gain per animal.

Certainly, improved pastures can increase both the animal production per head and per hectare by supplying higher yields of pasture of a higher quality, especially where the pastures contain persistent legumes (Stobbs 1975).

Meeting the targets proposed by FAO will require major changes in a number of areas. Firstly, the proportion of animal protein from pigs and poultry will increase because of their rapid reproductive rate. They are, however, largely dependent on cereal grains and protein concentrates and thus will compete with humans for this resource. It will mean that the increase in grain yields recorded over the past thirty years will need to continue to meet this need. The FAO envisages an increasing use of concentrates for ruminant feeding to increase the productivity per animal so necessary to meet the projected targets (Hrabovszky 1981). This may sound very strange to Australians and New Zealanders, but it may not necessarily mean that the grain is inefficiently used. In Table 6 the human edible energy and protein returns from feeding concentrates to dairy cattle, beef cattle and poultry are compared.

TABLE 6

Returns from feeding human edible concentrates to cattle and poultry in terms of human edible energy (E) and protein (P) return (After Bywater and Baldwin 1980)

Product	E (%)	P (%)
Milk	100	181
Beef	57	109
Poultry	31	75

It can be seen that herbivores give higher returns than poultry, since most of their diet would be non-human food compared with a high content of potentially human food in poultry diets. If the supply of concentrate feed can elevate production, then the maintenance charge per unit of production is decreased, and this could lead to increases in efficiency (Bywater and Baldwin 1980). Whether this will occur in the developing countries will depend on the price of grains (an indication of their availability) in relation to the price of animal products.

The impact of new technologies

Agriculture in general has benefited immensely from research in one form or another over the last two centuries. The application of this research has enabled world food production to exceed population growth over the last 30 years, particularly with cereal grains where, over the period 1954–1984, world population increased 79% and grain production by 183% (FAO Statistics 1955, 1985). Area cropped to grains increased by 46%, whereas yields increased by a massive 94% (Table 7).

TABLE 7

World population, production of cereals and world acreages devoted to cereals in 1954 and 1984 (FAO Statistics)

	1954	1984	Increase %
People ($\times 10^9$)	2.658	4.764	79
Bread and coarse grain production (t $\times 10^6$)	636	1802	183
Area cropped with grain (ha $\times 10^6$)	499	730	46
Yield of grain (kg/ha)	1272	2468	94

As noted earlier, the increase in productivity measured with animals has not occurred over this period in the developing countries and it is unlikely that this situation will change greatly in the near future. The major improvement in potential cereal yields has occurred by changing the ratio of grain to straw (the crop index) rather than any change in the rates of photosynthesis of newer varieties (Austin *et al.* 1980). With current technology, no such dramatic change in animal production can be anticipated by a shift in the energy metabolised to increase the edible portions of the grazing herbivores.

WHAT ARE THE PROSPECTS FOR THE FUTURE? CAN NEW TECHNOLOGY CONTRIBUTE TO ACHIEVING HIGHER PRODUCTIVITY IN THE GRAZING HERBIVORE?

Control of diseases and pests

It is the control of the serious epidemic diseases which have enabled intensive and, in some cases, extensive livestock industries to become established. Constant vigilance is needed, however, to prevent their recurrence, especially in developing countries, as the resurgence of rinderpest in Africa in the 1980s has shown (FAO 1983). Although the technical "know-how" to control most of the serious diseases of ruminants is available, the economic and social problems in applying these can be immense (Robertson 1975; Soni 1987). Even in developed countries, like Australia, not noted for having serious disease problems, the cost of pests and diseases can be high.

The cost of the cattle tick to the industry is estimated at > $100 million annually, and the cost of internal parasites as > $20 million annually (CSIRO 1987). In the sheep industry, foot rot is estimated to cost $60 million annually (Mattick 1986). Undoubtedly disease and pest control programs will become increasingly effective in the future. We are now seeing the beginning of what could be a revolution in the control of diseases for the grazing herbivore. Already genetically engineered vaccines have become available for foot-rot in sheep, and cattle have been successfully vaccinated against cattle tick in experiments (Johnston *et al.* 1986). The CSIRO Division of Tropical Animal Production is well advanced in its endeavours to produce a commercial vaccine to protect cattle from ticks (CSIRO 1987) and a similar program has commenced to produce a vaccine to protect cattle against the gastro intestinal nematode—*Oesophagostomum radiatum* and sheep from blowfly.

It can be expected that this approach will be used in attempts to control other economically important diseases and pests in the future. The numbers of tick species in other countries may provide a far greater challenge than that faced in Australia with only one major cattle tick species.

Currently it is the tsetse fly, vector of the deadly tripanosomiasis, that limits the use of domestic herbivores over large tracts of land in Africa—use of trypanotolerant breeds such as the N'Dama of W. Africa offers some solution to the problem (Starkey 1984), but ultimately suitable vaccines produced by genetic engineering should be a better solution (Murray *et al.* 1979 a,b).

Control of reproduction

Synchronization of heat for artificial insemination purposes, or the transfer of fertilized ova can now be readily achieved. Improvement of fertility in sheep has recently been induced by successfully immunizing ewes against androstenedione so that they produce a greater proportion of twins (Cox *et al.* 1982). Fecundin is now marketed commercially in Australia and results overseas have confirmed the Australian findings with ewes of average fertility. With the prolific East Friesland breed improvement was minimal (Rhind 1987) and perhaps unnecessary!

In the future, chemical castration and chemical speying could replace surgical procedures so countering some of the criticism from animal liberation groups.

Control of growth

Better understanding of nutritional requirements of grazing herbivores and of the feeding values of the plants they graze may enable more effective strategies for grazing management and mineral supplementation to be developed. The use of anabolic agents has led to increases in liveweight gain of steers of the order of 15–20%. This effect is the result of better N retention and growth of muscle. These substances have hormonal activity similar to the sex steroids. Combinations of androgens and oestrogens result in greater liveweight gain and better food conversion efficiency (Heitzman 1980). The effect of these compounds may be mediated through a second hormone such as insulin or growth hormone in the case of oestrogen, or through the thyroid hormones in the case of androgens (Heitzman 1980).

The use of exogenous growth hormone has resulted in dose related increases in milk production in both short term and longer term experiments. Feed intakes also increased in the longer term experiments (Thornton 1987). Commercial use of the hormone would be more appropriate under intensive, high producing enterprises and is unlikely to be used in developing countries. In the future the use of transgenic animals incorporating a gene for the production of growth hormone may be possible in grazing herbivores. The attraction of this approach is the increase in growth rate combined with a higher proportion of lean meat, which is demanded today, and higher milk production, provided that higher feed intakes can be maintained.

A strategy of relevance to the semi-arid areas is the reduction of weight loss in the dry season. Agents to decrease metabolic rate without adverse effects on the animal could be extremely useful in the stressful environments of the tropics. Is it possible that suitable agents could induce hibernation in ruminants—or perhaps a suitable gene be introduced to enable animals to survive the dry season without damaging the grazing resource?

Agents to modify rumen fermentation are now available commercially. In the future such agents will enable undersirable reactions to be controlled and favourable reactions to be promoted. Reduction in losses via methane and ammonia, antibotic action in the gut and promotion of propionate as opposed to acetate may all be involved in their action.

As more is known about the complex ecosystem of the rumen, so the possibilities for improvement in animal productivity by manipulation of the system could increase. Modification of the rumen micro-organisms to enhance fermentation, to destroy toxic secondary plant compounds and to utilise plant fibre more effectively are possibilities for the future. The potential for genetical engineering of rumen microbes for specific purposes is an exciting new development.

There may be naturally occurring bacteria in other environments that could be utilized. The finding that Australian ruminants, lacking DHP degrading bacteria and hence unable to use leucaena effectively in their diets, could be protected from leucaena toxicity by rumen infusion with DHP-degrading bacteria isolated from goats in Hawaii (Jones and Megarrity 1986), has demonstrated that introduced bacteria can survive and multiply in the rumen provided there are suitable substrates available that other bacteria cannot attack. Recently Dr. Orpin at Cambridge has isolated a particularly active cellulolytic bacterium from a reindeer. Genes from this strain have been cloned in *E. coli* for use in gene transfer experiments between bacteria (Orpin 1986).

It is interesting to note that the rumen ecosystem which has enabled the ruminant to be so successful is one that has been little modified by man. The complexities are great, but a greater understanding of the organisms involved and their interactions could prove to be the most rewarding chapter in the history of the grazing herbivore.

Genetic improvement

That animals differ in their ability to survive, grow, breed and utilise food efficiently is well known. That there are interactions between the environmental conditions and the ability to express the potential of these characteristics is also evident. Breeds with the capacity for high production are generally less tolerant of stressful environments. This antagonism between productive and adaptive characters (Vercoe and Frisch 1982) makes it difficult to combine high productivity with high levels of adaptation to environmental stress in one breed. The F_1 animal from an adapted and a productive breed does appear to combine the key attributes of both parents. This heterosis is well known but of limited usefulness in many practical situations. The use of F_1 females to produce F_1 offspring would appear to be the most efficient genotype combination. This is now possible with embryo transplants, but to my knowledge has never been used, even experimentally, to assess the superiority of the combination.

Local breeds in the developing countries are well adapted to their environment, but may lack characteristics for high production, particularly in terms of milk production. Introduction of established milking breeds was necessary to raise milk production for specialised enterprises, but improvements in the quality of the feed supply was also necessary. Other than for milk production and wool production, it is likely that the genetic potential of the indigenous livestock exceeds the ability of the pasture to provide sufficient nutrients for its expression ('t Mannetje 1983).

If the target requirement for animal products is to be met, the provision of extra food, preferably of higher quality, must be a major objective.

Improvement of feed supply

Of all the factors limiting increased productivity, lack of suitable feed is the most important. In the developed temperate areas of the world, deficiencies in feed supply and feed quality are compensated for by the use of stored fodder and of concentrate feeds with additions of necessary minerals (Reid and Jung 1982). In these areas the best adapted species have been selected over many years, fertiliser input for maximum production has been determined and efficient grazing strategies for utilising the pastures developed. The value of individual animals is so high that losses through poor management cannot be tolerated. Furthermore, high production per animal is an important objective, since it reduces the overhead costs of the maintenance requirement. Under these conditions, animals exist at maintenance levels of feeding for only short periods. Emphasis is on feed quality to maximise intake and the removal of anti-quality factors which reduce feed intake (Reid and Jung 1982).

In developing countries and in sub-tropical and tropical areas of the world subject to seasonal fluctuations in climate, animals may exist at maintenance levels of feeding for prolonged periods. It has been claimed that, in developing countries, most of the feed eaten by grazing herbivores is required for maintenance, with little left over for production—the food conversion efficiency (FCE) is therefore extremely low. Low total feed intake can be due to competition for the available feed (over stocking), to the low quality of the feed available, or both (see Fig. 4).

In his opening address to the Nutritional Limits to Animal Production from Pastures Symposium in Brisbane, Dr. Mahadevan (FAO) listed the major limiting factor for each region in the developing world—in all but one, feed shortage or overstocking was the major limiting factor to increased animal production. It seems certain that, in some of the heavily overgrazed areas, the production per hectare as well as production per animal has declined (Fig. 3). Under these circumstances, a reduction in the stock numbers should result in increases in feed supply and in both gain/animal and gain/ha. This strategy, however, is not likely to be adopted readily.

In areas of the semi-arid, sub-humid and humid zones, improvement of the pasture resources is the only alternative to de-stocking. Technology is available in S. America (Toledo 1985) and Australia (Eyles and Cameron 1985) as a result of research in the past 20–30 years to produce pastures with far higher yields and nutritive value than the native pastures. Legumes are the key to this development, combined with necessary inputs of fertilizer and possibly mineral supplements (Jones 1984).

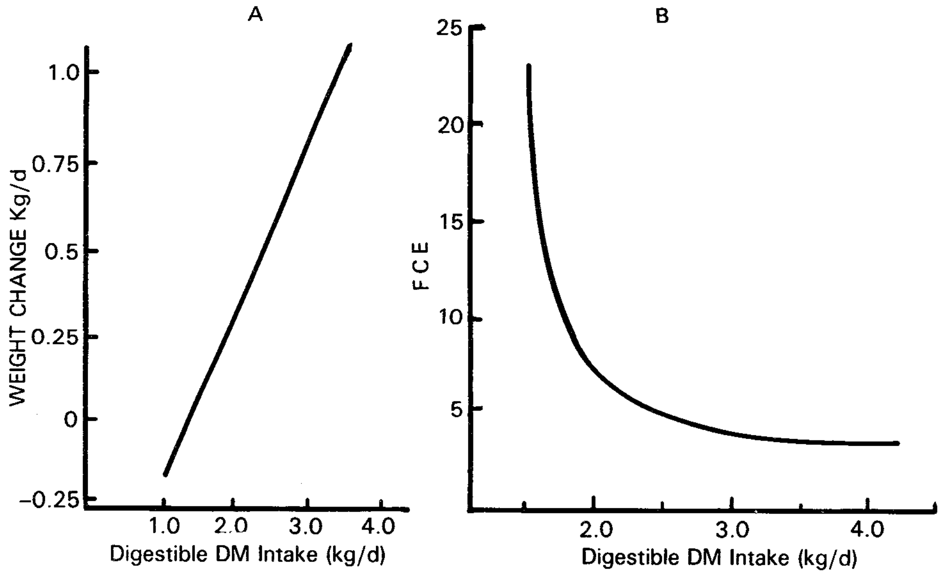

FIGURE 4

The relation between digestible dry matter intake (kg/d) and
A Liveweight change (kg/d).
B Food conversion efficiency (FCE) (kg food/kg gain).
(after Holmes *et al.* 1966).

The higher carrying capacity of these pastures could form the basis of a management system in which the native pastures are rested or grazed at lower pressure to aid recovery to a higher level of production. The principles for sown pasture development may well be applicable in Africa and elsewhere, provided persistent legumes can be found. Having a technology, however, is but a start, albeit a very necessary one. The social and economic problems involved in adopting the technology may be complex and not easy to overcome. The need for more animal products is, however, too great to ignore these difficult problems.

In the humid tropics and some semi-arid tropical areas where pasture resources are limited due to the intensity of cropping, the future for the grazing herbivore is in an integrated system with cropping (Mahadevan 1982). There are untapped resources in plantation agriculture for providing livestock products in conjunction with tree crops such as coconut and oil palm. Crop residues form an important, if not the most important, component of the diet of many domesticated herbivores in developing countries. These residues can be more efficiently used if they are supplemented with nitrogen (urea) and further benefits can be obtained through chemical treatment to render the feed more digestible. Technologies are available for such straw treatment, but they are not widely used. For a variety of reasons none could be unreservedly recommended for implementation in developing countries in 1976. In Asia the benefits of alkali treated straw under village conditions need further assessment in physical and economic terms (Jackson 1978). This message is obviously relevant in 1987 (Ibrahim and Schiere 1987).

Alternatives to chemical treatment to improve the value of straws include the use of supplements including leguminous fodders, especially shrub legumes or trees which may be lopped to provide both fodder and fuel wood. Such systems have been effective in Indonesia, where leucaena and other shrub species are being used to fatten animals or to supplement low quality roughages (Parera 1983; Nitis 1985).

THE IMPACT OF NEW TECHNOLOGIES ON THE GRAZING RESOURCES

Technologies which improve the chances of survival for livestock in the developing countries—disease control, nitrogen supplements, mineral supplements, the use of better adapted genotypes with better foraging ability or water use efficiency are all valuable for the grazing herbivore in the short term. Use of these techniques, however, has resulted in higher stock numbers, better survival through droughts and greater pressure on the grazing resource—in short, a similar response to that which followed improved health care and nutrition in the human population of developing countries. It is unlikely that animal populations will decline while human populations are still increasing. Control of both is essential if the ecosystems currently sustaining these populations are to be maintained. Ultimately, the populations of both run the risk of being reduced by starvation—a scenario which sadly is becoming all too common following sequences of drought years. In many developing countries where the stock are owned privately and the land held communally, voluntary reductions in stock numbers are not easily achieved. The consequences of overstocking on the rangeland resources are becoming increasingly apparent. Both contemporary and historical evidence indicates that most livestock managers in the grazing situation do not adjust their management to maintain the soil and vegetation resource (Williams 1981).

In the developing countries, the ownership pattern described above has been blamed—the so-called "tragedy of the commons" (Hardin 1968). In other situations, such as Australia, the possibilities of financial loss or reduced profit associated with the management decision may be the deciding factor. Under both conditions the resource suffers. The problem becomes a vicious circle. Once plant cover is removed, water infiltration is reduced, run-off causes erosion and plant growth is further limited.

Serious degradation of the arid and semi-arid pastures is now widespread and accelerating (Harrrington 1981). The major problem is that of numbers of people in these zones and the requirement for livestock to support them. The other problems of mismanagement stem from this primary problem.

THE IMPACT OF OTHER FACTORS

The energy crisis

Although currently there is a glut of oil and prices have stabilised somewhat, the supply is limited and prices are expected to rise again. This will have repercussions in many areas. Since it takes 2 kg of oil to manufacture 1 kg of N in a fertilizer (Blaxter 1986), economies with a high use of fertilizer N will be greatly affected, but so will those using superphosphate and legumes since oil is needed in the extraction process of phosphatic rocks.

Transport costs will also increase and so the replacement of herbivores with tractors and trucks will be slowed. In this role, the grazing herbivore appears to have a secure future in developing countries for many years.

Alternative food and fibre sources

A decade or more ago, synthetic meat products and synthetic materials caused considerable concern in the rural industries. The oil crisis has slowed the enthusiasm once shown, but through biotechnology, e.g., in single cell protein culture, cheaper forms of protein will become available, in the first instance, for the feeding of livestock. This may reduce the cost of poultry and pigs relative to other meats and indirectly reduce the demand for those meats. However, the great demand for meat and for meat-like, high-protein foods means that both these foods will be required to feed the world population. If these products become more widely available, it would seem that the exporting countries would be the first to suffer. Since only 10–11% of meat is traded internationally, overall production may not be seriously affected. There is certainly scope for increasing the variety of products from grazing ruminants to maintain or increase markets relative to synthetic products. Community trends to favour natural foods and other products could well counter the challenge from many synthetics.

Public opinion

There is an increasing comment by the non-rural sector on issues affecting the rural sector. The rise of the Animal Rights Movement and allied causes has drawn attention to what they perceive to be cruelty in the raising of farm animals. The grazing herbivores are a lesser target than the more intensively managed livestock, but extreme groups make it clear that they would like to see meat disappear from the diet of humans. More recently, opposition to the culling of kangaroos has been voiced internationally with calls to stop imports of Australian beef as a retaliatory measure.

The resistance to the use of growth promotants in Europe, in spite of expert evidence indicating no health risk to humans, reflects public attitudes in their desire to eradicate all possible forms of contamination which may be injurious to human health. The recent scare in Australia over high pesticide residues in meat sent to the USA and Japan further highlights the effect of public opinion on the trading of animal products.

Health risks associated with high levels of red meat in the diet is a continuing issue which may influence demand for meat in the future. These problems so far are confined to the more affluent countries—to the developing countries with only small amounts of meat in their diet the arguments are largely irrelevant. I fear that the cost of beef will also restrict intakes in other countries.

There is also a growing concern about feeding cereal grains to livestock (particularly beef animals) which could be used as human food or fed to monogastric animals. This has become a moral issue which could gain momentum if there are further serious droughts in the developing countries.

It is difficult to predict how public issues will eventually influence animal husbandry practices, but it may well be that some technologies for improving animal productivity will be withdrawn from use and others prevented from becoming commercial.

An issue which may become more prominent with time is that of land degradation. It is estimated that some 54,000 km^2 of land is being converted to desert each year (Dregne 1983). Reasons for this may be complex, but overgrazing is one contributing factor. Human and/or herbivore populations will need to be controlled to halt the degradation in developing countries and countries like Australia where herbivores are raised in semi-arid areas. Governments are often reluctant to grapple with these issues for political reasons. However, in a pre-election speech on 6th July, 1987 by Mr. Bob Hawke, Prime Minister of Australia, a promise was made that his government would endeavour to achieve 'total protection of the environment'. It is interesting to note that in the Middle East, goats have been banned from some areas, and in some parts of Indonesia grazing is not allowed—herbivores have to be tethered or penned because of potential damage to crops and to the land resource. In a world which is becoming increasingly conscious of environmental issues, it would be tragic if the grazing herbivore, which for so long has contributed to man's well-being, becomes identified as the major agent in land degradation. It will not be an indictment of the grazing herbivore, but of man who has failed to be the responsible custodian of the variety of ecosystems on which they and he ultimately depend.

As scientists we must meet this enormous challenge.

I close this lecture by reference to a most unusual grazing herbivore—the ostrich. It has lost its power of flight, its sheer bulk keeps it earthbound, and hence its perspective is limited; the ostrich feathers (for which it was once most prized) have gone out of fashion, its product has become irrelevant to society's needs and, finally, it had a reputation (quite wrongly) for burying its head in the sand when problems arose!

Perhaps there are warnings for us, as scientists, as well as for politicians, as we seek to contribute to the future of our grazing herbivores.

REFERENCES

ABARE (1988)—Quarterly review of the rural economy **10:** 95–114.

Austin, R. B., Bingham, J., Blockwell, R. D., Evans, L. T. and Ford, M. A. (1980)—Genetic improvements in winter wheat yields since 1900 and associated physiological changes. *Journal of Agricultural Science* **94:** 675–689.

Australian Bureau of Statistics (1985)—Year Book of Australia No. 69. Australian Bureau of Statistics, Canberra.

BAE (1986)—Commodities Statistical Bulletin, Bureau of Agricultural Economics, Canberra, December 1986.

Barat, S. K. (1975)—Hides, skins and animal by-products—Directions for Development. *World Animal Review* **14:** 20–25.

Blaxter, Sir Kenneth, FRS (1986)—Food and People. *In:* XIIIth International Congress of Nutrition, Brighton, U.K. 1985. Human Nutrition: Clinical Nutrition **40C,** 95–102.

Bywater, A. C. and Baldwin, R. L. (1980)—Alternative Strategies in Food-Animal Production. *In:* Animals, Feed, Food and People—An Analysis of the Role of Animals in Food Production (Ed. R. L. Baldwin) pp. 1–30. (Westview Press, Inc.: Boulder, Colorado).

Cox, R. I., Wilson, P. A., Scaramuzzi, R. J., Hoskinson, R. M., George, J. M. and Bindon, B. M. (1982)—The active immunization of sheep against oestrone, androstenedione or testosterone to increase twinning. Proceedings of the Australian Society of Animal Production **14:** 511–514.

CSIRO (1987)—Annual Report of The Division of Tropical Animal Production (in press). CSIRO: Australia.

Dregne, H. E. (1983)—"Desertification of arid lands" (Harwood: New York).

Drew, K. R. and Bigham, M. L. (1987)—Recent developments in deer and goat farming in New Zealand. Proceedings of the 4th AAAP Animal Science Congress, Hamilton, N.Z. pp. 90–93.

Eyles, A. G. and Cameron, D. G. (1985)—Pasture Research in Northern Australia—its history, achievements and future emphasis (Ed. J. B. Hacker). Research Report No. 4; CSIRO Division of Tropical Crops and Pastures. CSIRO: Australia.

FAO (1983)—Food and Agriculture Organization. World Animal Review Special Supplementary Issue on Rinderpest. p. 32.

FAO Statistics (1955)—Yearbook of Food and Agricultural Statistics Pt. 1: Production v. 8 1954, 347 p.

FAO Statistics (1985)—Series No. 61 FAO Production Yearbook Vol. **38,** p. 326.

Frith, H. J. (1970)—The Herbivorous Wild Animals. Australian Grasslands (Ed. R. Milton Moore). Australian National University Press pp. 74–83.

Gonzalez, E. and Parra, R. (1973)—The capybara, a meat producing animal for the flooded areas of the tropics. IIIrd World Conference on Animal Production. Australia, Sydney University Press. pp. 81–86.

Hardin, G. (1968)—The tragedy of the commons. *Science* **162:** 1243–1248.

Harrington, Graham N. (1981)—Grazing Arid and Semi-Arid Pastures. *In:* World Animal Science, B1 Grazing Animals (Ed. F. H. W. Morley) (Amsterdam: Elsevier.) pp. 181–202.

Heitzman, R. J. (1980)—Growth stimulation in ruminants. *In:* Recent Advances in Animal Nutrition. Eds. W. Haresign and D. Lewis. (London: Butterworth).

Henzell, E. F. (1983)—Contribution of Forages to Worldwide Food Production: Now and in the Future. *In:* Proceedings of the XIV International Grassland Congress (Eds. J. Allan Smith and Virgil W. Hays) Lexington, Kentucky, U.S.A. pp. 42–47. (Westview Press: Boulder, Colorado.)

Hill, B. E. (1972)—The world market for beef and other meat. *World Animal Review* No. 4. pp. 1–6.

Holmes, J. H. G., Franklin, M. C. and Lambourne, L. J. (1966)—The effects of season, supplementation and pelleting on intake and utilisation of some sub-tropical pastures. Proceedings Australian Society for Animal Production Vol. VI. pp. 354–363.

Hoppe, P. P. (1984)—Strategies of digestion in African herbivores. *In:* Herbivore Nutrition in the Subtropics and Tropics (Eds. F. M. C. Gilchrist and R. I. Mackie) pp. 221–243. The Science Press (Pty) Ltd. South Africa.

Hrabovszky, J. P. (1981)—Livestock Development: Toward 2000 With special reference to developing countries. *World Animal Review* **40:** 2–40.

Hudson, R. J. and Bunnell, F. L. (1981)—Grazing in Tundra and Northern Boreal Environments. *In:* World Animal Science, B1 Grazing Animals (Ed. F. H. W. Morley) Amsterdam: Elsevier. pp. 203–223.

Hume, I. D. (1987)—Native and introduced herbivores in Australia. *In:* The Nutrition of Herbivores (Eds. J. B. Hacker and J. H. Ternouth). pp. 1–22. Academic Press: Australia.

Ibrahim, M. N. and Schiere, J. G. (1987)—Animal production possibilities using fibrous residues. The 4th AAAP Animal Science Congress, Hamilton, N.Z. pp. 74–77.

Jackson, M. G. (1978)—Treating straw for animal feeding—an assessment of its technical and economic feasibility. *World Animal Review* **28:** 38–43.

Jana, D. N. and Chaudhuri, D. (1985)—Bullock power in India. *World Review of Animal Production,* Vol. XXI, No. **4,** October-December 1985.

Johnston, L. A. Y., Kemp, D. H. and Pearson, R. D. (1986)—Immunization of cattle against *Boophilus microplus* using extracts derived from adult female ticks: effects of induced immunity on tick populations. *International Journal for Parasitology* **16:** 27–34.

JONES, R. J. (1984)—Improving the Nutrition of Grazing Animals using Legumes, Fertilizer and Mineral Supplements. *In:* Proceedings of the Eastern Africa-ACIAR Consultation on Agricultural Research, 18–22 July 1983, Nairobi, Kenya.

JONES, R. J. and MEGARRITY, R. G. (1986)—Successful transfer of DHP-degrading bacteria from Hawaiian goats to Australian ruminants to overcome the toxicity of Leucaena. *Australian Veterinary Journal*, **63:** 259–262.

JONES, R. J. and SANDLAND, R. L. (1974)—The relation between animal gain and stocking rate. Derivation of the relation from the results of grazing trials. *J. agric. Sci.* Camb. **83:** 335–342.

JOUBERT, D. M. (1984)—The herbivore in tropical and subtropical Africa—Keynote Address—*In:* Herbivore Nutrition in the Subtropics and Tropics (Eds. F. M. C. Gilchrist and R. I. Mackie). pp. 17–25. The Science Press (Pty) Ltd: South Africa.

JUL, M. and PADDA, G. S. (1984)—Meat Production in India: The Potential of Buffalo Beef. *World Animal Review* **50:** 36–44.

KING, J. M. and HEATH, B. R. (1975)—Game domestication for animal production in Africa. *World Animal Review* **16:** 23–30.

LANGER, P. (1984)—Anatomical and nutritional adaptations in wild herbivores. *In:* Herbivore Nutrition in the Subtropics and Tropics (Eds. F. M. C. Gilchrist and R. I. Mackie) pp. 185–203. The Science Press (Pty) Ltd. South Africa.

LOWE, PETER (1986)—Animal Powered Systems. Marketed and distributed by John Wiley & Sons Ltd. 60 pp.

McDOWELL, ROBERT E. (1980)—The Role of Animals in Developing Countries. *In:* Animals, Feed, Food and People—An Analysis of the Role of Animals in Food Production (Ed. R. L. Baldwin) pp. 103–120. Westview Press, Inc. Boulder, Colorado.

MAHADEVAN, P. (1982)—Pastures and Animal Production. *In:* Nutritional Limits to Animal Production from Pastures (Ed. J. B. Hacker). pp. 1–17. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

T' MANNETJE, L. (1984)—Nutritive value of tropical and subtropical pastures, with special reference to protein and energy deficiency in relation to animal production. *In:* Herbivore Nutrition in the Subtropics and Tropics (Eds. F. M. C. Gilchrist and R. I. Mackie). pp. 50–66. The Science Press (Pty) Ltd: South Africa.

MATTICK, J. (1986)—Recombinant Footrot Vaccine in Commercial Development. *Biotech* **1:** 5.

MORRIS, G. J. and YOUNG, M. D. (1987)—Economic and Administrative Influences on Kangaroo Management in NSW. Third Report. CSIRO Division of Wildlife & Rangelands Research, Deniliquin. 46 p.

MURRAY, M., BARRY, J. D., MORRISON, W. I., WILLIAMS, R. O., HIRUMI, H. and ROVIS, L. (1979a)—A review of the prospects for vaccination in African *trypanosomiasis*—Part I. *World Animal Review* **32:** 9–13.

MURRAY, M., BERRY, J. D., MORRISON, W. I., WILLIAMS, R. O., HIRUMI, H. and ROVIS, L. (1979b)—A review of the prospects for vaccination in African *trypanosomiasis*—Part II. *World Animal Review* **33:** 14–19.

NITIS, I. M. (1985)—Present state of grassland production and utilization and future perspectives for grassland farming in humid tropical Asia. *In:* Proceedings of the XV International Grassland Congress August 24–31 1985 Kyoto Japan. pp. 39–44.

ORPIN, C. G. (1986)—Molecular biology of ruminal and other anaerobic bacteria. Institute of Animal Physiology Report for 1984 and 1985. Agricultural and Food Research Council: London. p. 84.

PARERA, V. (1983)—Leucaena for erosion control and green manure in Sikka. Leucaena research in the Asian-Pacific Region: Proceedings of a workshop held in Singapore, 23–26 November, 1982. IDRC Ottawa, Ont. pp. 169–172.

PEDEN, D. G. (1987)—Livestock and wildlife population distributions in relation to aridity and human populations in Kenya. *Journal of Range Management* **40:** 67–71.

REID, R. L. and JUNG, G. A. (1982)—Problems of animal production from temperate pastures. *In:* Nutritional Limits to Animal Production from Pastures (Ed. J. B. Hacker). pp. 21–43. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

REUL, R. H. (1979)—Productive potential of wild animals in the tropics—a review of the literature. *World Animal Review* **32:** 18–24.

RHIND, S. M. (1987)—A note on the reproductive performance of ewes of different genotypes following active immunization against androstenedione. *Animal Production* **44:** 326–329.

ROBERTSON, A. (1975)—The Future of Animal Production: Animal Health. *In:* Proceedings of the III World Conference on Animal Production (Ed. R. L. Reid) Sydney University Press pp. 490–95.

SHEPHERD, N. C. (1983)—The feasibility of kangaroo farming. *Australian Rangelands Journal* **5:** 35–44.

SONI, B. K. (1987)—Animal Disease Control Programmes in Tropical South and Southeast Asia. Proceedings of the 4th AAAP Animal Science Congress, Hamilton, N.Z. pp. 94–97.

STARKEY, P. H. (1984)—N'Dama cattle—a productive trypanotolerant breed. *World Animal Review* **50:** 2–15.

TALBOT, L., PAYNE, W., LEDGER, H., VERTCOURT, D. and TALBOT, M. (1965)—The meat production potential of wild animals in Africa. CAB Farnham Royal, Bucks. U.K.

THORNTON, R. F. (1987)—The partitioning of nutrients by herbivores. *In:* The Nutrition of Herbivores (Eds. J. B. Hacker and J. H. Ternouth). pp. 307–331. Academic Press: Australia.

TOLEDO, J. M. (1985)—Pasture development for cattle production in the major ecosystems of the tropical American lowlands. *In:* Proceedings of the XV International Grassland Congress August 24–31 1985 Kyoto Japan. pp. 74–81.

UNFPA (1987)—United Nations Fund for Population Activities. State of World Population report.
VERCOE, J. E. and FRISCH, J. E. (1982)—Animal breeding for improved productivity. *In:* Nutritional Limits to Animal Production from Pastures (Ed. J. B. Hacker). pp. 327–342. Commonwealth Agricultural Bureaux, Farnham Royal, UK.
WILLIAMS, O. B. (1981)—Evolution of Grazing Systems. *In:* World Animal Science, B1 Grazing Animals (Ed. F. H. W. Morley) Amsterdam: Elsevier. pp. 1–12.
WOODFORD, K. (1987)—Deer Farming Prospects—An Address to the Queensland Branch of the Australian Institute of Agricultural Science 22 April 1987. University of Queensland, St. Lucia.