Production and Use of Feed for Sustainable Animal Production in Australia* - Review -

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ABSTRACT : This paper summarizes the size and output of the major animal industries in Australia and the feed resources available to maintain production. The most important feed source is pasture but there is also extensive use of cereal grains, pulses and by-products in the intensive animal industries and in supplementing the diet of grazing animals. These resources must be used in ways that ensure sustainable production. We outline a number of Decision Support Systems such as GrazFeed, GrassGro, and AusPig which play an important role in optimizing the way in which resources are used. Waste management with respect to mineral pollution of water courses and methane production as a greenhouse gas are important issues for the animal industries and are also considered. *(Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 3 : 435-444)*

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INTRODUCTION

This paper discusses the production and utilization of various feeds for the major types of farmed livestock in Australia (table 1) and the strong emphasis placed on the sustainability of livestock enterprises and their harmony with the environment.

Table 1. Livestock numbers and production in Australia, 1997

Species		Number	Production	
		(million)	Commodity	(million)
Dairy cattle		2.0	Milk	8715L
Beef cattle	Total (>1yr of age)	23.3	Beef	1.78t
	Feed lot	0.5		
Sheep		120.3	Mutton	0.308t
			Lamb	0.275t
			Wool	0.730t
Pigs		2.6	Pork	0.325t
Poultry	Layer	10.3	Eggs	2090
	Meat birds	63.7	Chicken meat	0.532t

Source: Australian Bureau of Statistics, Canberra.

The largest Australian animal industries in terms of land use, size and export potential are those based on pasture production and include beef cattle, sheep for wool and meat production, and dairy cattle. The intensive pig and poultry industries are significant in their own right but currently cater mainly for the domestic market. There is a considerable number of other types of farmed livestock, but relative to those shown in table 1 these enterprises are rather small. They include the farming of goats, mainly for Cashmere and Angora fibres but increasingly for milk and meat; also farmed are deer, buffalo, alpaca, emu, ostrich, crocodile, and freshwater and marine fish, crustaceans, and molluscs. The gross value of Australian agricultural production in 1995/96 was AUD 27.4 billion of which nearly half was animal products. Most of the wool produced (AUD 2.6 billion) and much of the meat and milk/milk products (AUD 6.2 and 3.0 billion respectively) were exported.

FEED RESOURCES

Pastures

The majority of Australia's cattle and sheep obtain all or most of their feed by grazing the indigenous and introduced plant species in the nation's tropical and sub-tropical, arid and semi-arid, temperate, and Mediterranean climatic regions. In many areas, rates of pasture growth are reduced during winter with its frosts and consequent low soil temperatures. However, in these areas as in all of Australia the growth is determined overwhelmingly by rainfall. Rainfall is always highly variable within and between years, whether or not there is an El Nino event.

There are general patterns of rainfall. In the tropical north there are distinct wet and dry seasons, the wet being of rather uncertain duration and intensity. In the Mediterranean climate of Western Australia, South Australia, and Victoria, new growth of pasture commences with the onset of the autumn break rains. These may be delayed, or cease for a period before resuming; as a result, a proportion of the seeds of annual grasses (e.g., *Lolium* spp.) and legumes (predominantly *Trifolium subterraneum*, subclover) may germinate and die during this false break. In the temperate climate zone of south-eastern Australia, the Tablelands with elevations up to about 1000m, there are rainfalls throughout the year but here too their

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occurrence and magnitude are uncertain.

In any given area of Australia there is, therefore, high variability both within and between seasons of year in the amount of feed provided by pastures, and in its nutritive value. At some times there is abundant feed of high digestibility that sustains high rates of animal production but these conditions occur for periods of weeks rather than months. More often the production of animals is constrained, and sometimes very severely because of drought, by the poor quantity or poor quality of pasture available, or by both circumstances, for periods varying in frequency and duration.

There are continuing efforts to improve the feed base, both the nutritional value of pasture herbage (e.g., the metabolizable energy, ME, and the protein contents of the dry matter, DM) and the regularity of supply of feed for grazing. Nutritional value of a grassy pasture is increased by the presence of a legume, both from its intrinsic nutritional worth and from its contributions via rhizobia of N to the grasses. There are numerous indigenous legume species in Australian pastures, but introduced species are much more important. Subclover, now carefully selected for low oestrogenicity, is an indispensable component of the annual pastures in the Mediterranean regions; after the growing season and when the plants have died, the seed is a major source of feed for sheep. This clover is also important in more northerly pastures, including the temperate area pastures which include white clover (*T. repens).* The white clover, however, rarely persists strongly through the heat and dryness of summer; much regeneration is from seed, and so this species often behaves as an annual. Attempts to establish a perennial clover that could be more persistent because it is rhizomatous (e.g., cicer milk vetch, *Astragalus cicer*; Caucasian clover, *T. ambiguum*; crown vetch, *Coronella varia*) have met with some, but at present rather limited, success. Lucerne (*Medicago sativa*), which is deep-rooted, requires careful grazing management to avoid damage to the crown that injures or stops regrowth. Among legumes for tropical pastures, *Stylosanthes* spp. can make major contributions if it is not infected by and is resistant to the fungal disease anthracnose (*Colletotrichum gloeosporoides*). This legume tolerates lower soil phosphorus than is required by many legumes. Australian soils generally are innately low in P, and often in sulphur, and applications of phosphatic fertilizers are essential for the establishment and maintenance of improved leguminous pastures.

Hay and silage

There are often periods of the year when pasture production exceeds the immediate requirements of the grazing animals. This surplus can be used by preserving it as silage or hay, or by leaving it in the field to mature and dry off as standing feed. The latter option of doing nothing and using the dry feed later is the cheapest although there will be considerable, and perhaps very high, losses in its quality and quantity before and when it is used because of leaching, microbial degradation, and trampling.

Fodder conservation, and the growing of forage crops for use during later periods of feed shortage, require careful integration into a grazing enterprise because their immediate effect is to reduce the area on a farm that is available for grazing. A stocking rate that is reasonable for the farm as a whole might become injudiciously high on the pasture areas remaining during the period that the fodder and forages are being grown. In those circumstances there could be a reduction in production by the animals, and prevention of feed conservation by the animals themselves in the form of increased body reserves (Wheeler, 1981). These effects, and the losses in amount and quality from conserved fodder that will occur during harvest, storage and feedout could, in sum over the whole period of preparation and feeding back, result in no overall increase in animal production; for all the effort and costs involved there could even be a negative economic return. Nevertheless, it is most desirable to level out the feed supplies.

As shown in table 2, there is substantial production of hay and silage. Silage has some important advantages compared with hay as a means of preserving surplus feed for strategic utilisation at a later date. Generally, herbage can be cut and stored as silage at an earlier stage of growth when nutritional value is higher. This benefit is preserved through the ensiling process if this is well managed, in particular quickly achieving and maintaining oxygen-free conditions, and there should be no more than a 15 to 25% loss of crop dry matter (Moran, 1996). It is also easier to keep silage for long periods.

Table 2. Annual hay and silage production in Australia 1989-1993

Type	Million tonnes (as fed)
Pasture hay	3.26
Cereal hay	1.21
Lucerne hay	0.81
Total hay	5.28
Total silage	0.82

(Kaiser, 1996)

The area of pastures and crops cut annually for hay, about 1.36 million hectares, is about ten times the area cut for silage. About 11% of the hay area is lucerne, but this provides a much higher proportion of total hay because it is usually an irrigated crop and grown for sale, and the lucerne hay is usually of high quality (i.e., 9.5 MJ of ME per kg DM, or more).

In Australia most hay is fed out in the year it is made and very little is kept for use in exceptionally dry years. The nutritional value of much of the hay other than lucerne is low because it has been harvested when too mature, and poor techniques have resulted in DM losses of 20 to 40% or more and even higher losses in nutrients. Such hay is not suitable for production feeding. It is suited to maintenance of body weight rather than growth, but the use of hay for this purpose in drought feeding is a very poor strategy because one is then compelled to keep feeding until the drought breaks or, perhaps from necessity, the stock are sold when prices may be low. On the other hand a production feeding program based on silage will finish stock for market, thereby reducing the grazing pressure and bringing cash flow to the enterprise. Despite the advantages of silage over hay, there is considerably more forage conserved as hay than as silage (table 2). This is partly for historical reasons, but it is also associated with the easier handling of hay using conventional farm equipment. This issue is of declining importance as increasing use is made of contractors, and there is a consistent trend towards greater use of silage.

Shrubs and trees

Deep rooting shrubs and trees are becoming increasingly important in some parts of Australia because they provide a more stable year-round source of nutrients for grazing animals than can be achieved by grasses and pasture legumes. The three most important species are salt bush (*Atriplex* spp.), *Leucaena leucocephela*, and tagasaste or tree lucerne (*Chamaecystisus proliferus*).

Saltbush, as the name implies, is tolerant of saline soils that occur naturally in large areas of inland Australia where it is a major feed source for many sheep kept primarily for wool production. It has played an important role in the management of salinity associated with rising water tables in parts of Australia cleared of trees for crop production. Saltbush survives and grows under conditions of low and variable rainfall but it is of rather low nutritional value, more suited for survival feeding and for wool production than for the growth of young animals for meat.

Leucaena is a tropical legume which can be grown under intensive management and irrigation to support stocking rates of seven cattle/ha throughout the year, or in dry land conditions to be used strategically when pastures are providing little feed and/or are of low nutritional value. Leucaena contains the amino acid mimosine, itself moderately toxic, which is converted by microbial activity in the rumen to the goitrogenic substance 3,4-dihydroxypyridine (DHP). The problems this caused in Australian cattle have largely been resolved by the introduction from overseas of ruminal bacteria that degrade DHP (Pratchett et al., 1991). Although leucaena is resistant to many pests and diseases there can be reduced production through thrip infestation and loss of trees and from fungal root diseases, particularly under conditions of irrigation.

Tagasaste was introduced to Australia from the Canary Islands and has established and grown well particularly in the Mediterranean areas of south western Australia. Like leucaena it is a deep rooting legume and remains green throughout the year. In the deep sandy soils of Western Australia, with annual rainfall down to 350 mm, tagasaste has performed remarkably well to provide feed, to protect against erosion from both wind and water, and to lower the water table. It is also able to grow well with surprisingly little fertiliser input as it extracts nutrients efficiently from a considerable depth which facilitates cycling of nutrients even on porous sandy soils. In parts of Western Australia, land considered suitable for 2 sheep/ha on annual pastures can carry 1 cow-calf unit/ha under tagasaste.

While saltbush is a genuine shrub and can be easily managed by grazing sheep, leucaena and tagasaste grow into trees and their management for efficient use by grazing animals can be a major constraint. Mechanical cutting of the trees is expensive (approx AUD40/ha) and is also wasteful in terms of the feed that is lost in this process. In order to utilise leucaena by grazing cattle a rotation is required to allow regrowth to occur. This system also needs careful adjustment of stocking rates to ensure that utilisation and new growth are closely matched. Tagasaste can be grazed continuously by cattle even in the dry summer months. When heavily grazed under dry conditions the plant is thought to produce high levels of phenolic compounds which limit intake and prevent defoliation.

Many of the shrubs and trees which have the potential to produce throughout the year contain tannins, phenolics or other anti-nutritional compounds primarily as a protection against insects and grazing animals. These anti-nutritional factors often reduce the palatability of the plant and limit intake and performance. While the adverse effect of tannins can partially be overcome through use of polyethylene glycol, this does not constitute a practical or cost-effective solution to low growth rates on these shrubs. Bacterial detoxification has been successfully applied in the case of mimosine in leucaena, and recent work at UNE (Gregg et al., 1997) has shown that the deadly chemical fluoracetate, present in a number of Australian shrubs, can be detoxified by genetically modified strains of the rumen bacterium *Butyrivibrio fibrisolvens*. The success of this approach is encouraging for future management of other anti-nutritional factors and toxins present in plant species which would otherwise be valuable for animal feeding.

Cereal stubbles

Australia produces around 30 million tonnes of grain each year and associated with this are about 50 million tonnes of crop residue remaining in the fields after harvest. This is an important feed resource for two reasons. Firstly it is available during the driest part of the year, particularly in the Mediterranean climate zones, and allows stock to be carried at a time when pasture feed resources are depleted. Secondly, because of the very fibrous nature and low nutritional value of the stem material it is very difficult to overgraze a cereal stubble paddock to the point where erosion is a serious risk. On the other hand if the crop residue is harvested mechanically or burnt there is a far higher risk of erosion. After sheep or cattle have consumed the spilt grain, leaf and husk material remaining after harvest, it is essential that they receive a source of supplementary nutrients to prevent weight loss which occur if grazing stubbles alone. Provided there is any green material in the form of pasture, weeds or shrubs there is unlikely to be a response to urea or mineral blocks. Grazing animals have a remarkable ability to find and eat green vegetation (e.g., weeds). One example, reported by Mulholland et al. (1976), was of sheep searching cereal stubbles so effectively that their diet was 80% green feed although the amount present was only 40 kg DM/ha among several tonnes of dry straw.

Grains oilseeds and pulses

Australia uses about 9 Mt of the grain it produces for domestic consumption, and there is a net export of around 20 Mt. Contributions of various grains to the total production, the domestic use, and size of exports are summarized in table 3.

Table 3. Production and use of Australian grains (Mt) in the 1992/93 and the 1997/98 seasons

Grain	Production and Use	1992/93	1997/98
Wheat	Production	16.18	18.55
	Domestic use-Human	1.80	1.96
	animal feed	2.01	2.60
	others*	2.03	0.79
	Net export	10.34	13.20
Barley	Production	5.40	5.92
	Domestic use-Human	0.17	0.15
	animal feed	1.40	1.50
	others	0.15	0.14
	Export	3.10	4.58
Oats	Production	1.94	1.30
	Domestic use-Human	0.09	0.11
	animal feed	1.52	1.02
	others	0.06	0.04
	Export	0.26	0.12
Triticale	Production (all domestic use)	0.28	0.41
Rice	Production	0.95	1.20
Sorghum	Production	0.55	1.32
	Domestic use	0.48	1.05
	Export	0.07	0.27
Maize	Production	0.20	0.33
Canola	Production	0.18	0.82
	Domestic use (crushers)	0.13	0.32
	Export	0.05	0.49
	Canola meal	0.07	0.18
Lupin	Production	1.20	1.38
	Export	0.81	0.97
Field peas	Production	0.46	0.30
	Export	0.35	0.16
Chickpeas	Production	0.18	0.19
	Export	0.18	0.17

Source: Australian Crop Report, February 1998. (Australian Bureau of Agricultural and Resource Economics: Canberra).
* 'Other' includes change in stocks and use for seed.

Wheat is the most significant crop for both the domestic and export markets. Of the five million tonnes used domestically approximately 2.5 Mt are consumed by livestock. The major grain used in the Australian feedlot industry is barley, with sorghum and wheat also being very important. Barley is also the most important grain in the dairy industry; wheat is the grain of major importance in poultry and pig industries. Oats are primarily used for feeding sheep although significant quantities are also used in cattle feeding. A small proportion of oats is de-hulled, the kernel being used for monogastric feeding and the hulls incorporated in ruminant diets.

The use of feed grains by the various animal industries is summarized in table 4. Increases in use are predicted for both the beef and dairy cattle industries relative to pigs and poultry. The importance of feedlot beef production is increasing in response to consumer demand for a product of consistently high quality. The increase in grain use for dairy production is a result of a move towards increased productivity per cow in order to optimize profitability. Production from Australia's pig and poultry industries is aimed principally at domestic consumption and is not expected to show much change in coming years.

Table 4. Use of feed grain in Australia by livestock type

Species	1997/98	1999/2000
Pigs	19	18
Poultry	23	22
Beef cattle	25	26
Dairy cattle	18	20
Sheep	5	5
Other animals	10	10

(Meyer Report, 1995)

There are potential problems in using cereal grains as supplements to increase the energy density of ruminant diets arising from the rapid microbial fermentation of starch which decreases the pH in the rumen (Terry et al. 1969) so that bacterial cellulolytic activity is increasingly inhibited. Fermentation of the roughage component of the diet is reduced, and as well as lower digestibility there is also lower feed intake. This point is well illustrated by the study of Godfrey et al. (1993) comparing the response in liveweight gain to supplements of barley (high-starch cereal) and lupin grain (a legume grain containing little or no starch). Figure 1 shows that when, with increasing interval of feeding, more grain was given on each feeding day the large amounts of barley fed at twice weekly (700 g) or weekly intervals (1.4 kg) were used less efficiently than when fed in smaller amounts every day (200 g). On the other hand there was little detrimental effect of feeding lupin grain even at intervals of 14 days (2.8 kg). Recent research on the problem of fermentative acidosis associated with feeding cereal grain to ruminants has shown that the use of virginiamycin effectively reduces the problems of lactic acid accumulation when feeding grain (Rowe and Zorrilla- Rios 1993) and allows efficient use of barley fed at weekly intervals (figure 1).

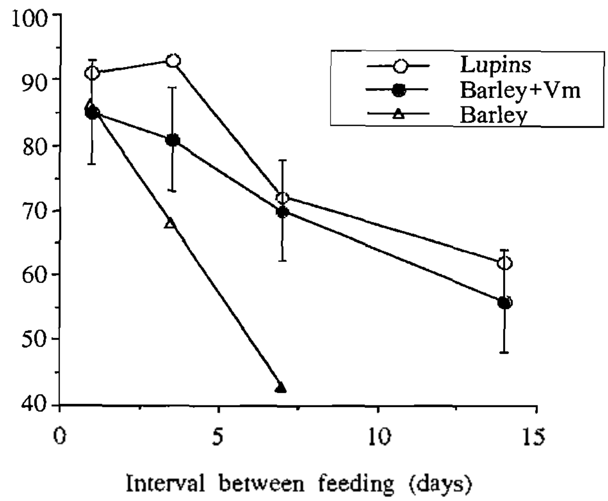

Figure 1. The effect of feeding barley or lupin grain daily, twice weekly, weekly or fortnightly at levels equivalent to 200 g/d to animals with free access to hay containing 1.5% urea. The barley was fed with or without virginamycin (Vm). The bars represent the standard error of the difference between treatments. (Godfrey et al., 1993)

The economic benefits of using cereal grain for animal feeding, and the demand for high quality animal products by consumers, have overwhelmed the ethical issues of using resources for this purpose when humans in many countries are dying from starvation. While it is likely that the economic forces will continue to predominate in determining the uses of grain, the future costs of grain, and of grain-based systems of animal production, are likely to rise significantly. This will result from higher production costs as fertilizer and energy prices rise, decreasing availability of productive arable land due to urbanization and degradation by erosion or from other causes, greater restrictions on fertilizer use in the management of river catchments, and a greater demand for grain by an expanding population. The long term viability of grain-based systems of animal production needs careful evaluation in terms of the most strategic and cost-effective use of grain. As a result of drought conditions in 1994/95, Australia imported grain for animal feeding in 1996. This was a significant step as the grain was principally used to sustain feedlot production rather than as disaster relief for starving livestock affected by drought. This importation and use of grain emphasizes the economic importance of consumer demand in determining the use of increasingly scarce grain resources.

By-products

Apart from the fibrous residues of cereal crop production, described earlier, the major by-products in Australia are from the cotton and sugar industries. Annual production of cotton seed is about 0.9 Mt, and this and cotton seed meal are very important sources of protein and are extensively used in dairy and beef production. Molasses, 1.2 Mt produced annually with about half exported, is widely used as a feed supplement in complete mixed diets as well as in mixtures with urea for grazing animals. Although there is minor use of bagasse for animal feeding this constitutes a relatively minor use of this fibrous material. Treatment of bagasse with alkali and/or steam to improve its digestibility is generally not cost-effective and most bagasse is burnt to produce electricity. While meat meal, blood meal and bone meal have been important by-products in the animal industries, the risk of prion diseases such as bovine spongiform encephalopathy is likely to result in the complete exclusion of these feeds from use. By-products of the food processing industries are used by several animal industries although these are generally small users and are located close to the factories. Brewers grains is quantitatively the most important food industry by-product and is a valuable feed for the dairy and feedlot industries located close to breweries.

SUSTAINABLE ANIMAL PRODUCTION

Animal production enterprises must be profitable to be sustainable, but must also ensure continuing viability of the natural resources that they directly employ and that, more widely, may be affected by their activities.

Pastures

The number of grazing livestock on a farm is primarily dependent on the rate of production of feed by the pastures during the season when their growth is slowest, and then by the extent to which strategies to level out the feed supply through the year by the use of supplementary feeds or other means are economically viable. Drought conditions, inevitably experienced by each generation of farmers in any given region several times at irregular intervals over years, pose in its severest form the continuing challenge of pastoral production. The continuing challenge is to strike a balance between inefficient use of pasture, because of understocking, and over-grazing, resulting in land degradation, so as to maximize profitable animal production on a continuing basis.

Greatest production per hectare is obtained when stocking density is increased so that individual animal production over whole grazing seasons is decreased towards one-half of the maximum achievable at so low a stocking rate on the same pasture that herbage quantity was always non-limiting. The maximum achievable production for a given animal genotype will vary between pasture types according to the nutritional quality of the herbage. The rate of decline from the maximum with increasing stocking rate reflects the rate of growth of the herbage, as determined by features of soil and climate and plant responses to grazing (Corbett, 1976).

In practice, the nutritional management of grazing animals to maximize profitable production presents complex problems. For example, when should the various pastures on a farm be brought into use, and how managed, in order to finish animals for slaughter, or to fulfil a commitment for milk production, or to grow young stock for entry to a feedlot at a required rate of gain to a required liveweight or, if female, so that there is no untimely delay in the development of reproductive ability? To achieve these goals, should grain or forage supplements be used though they will certainly be more costly feeds than pasture?

Nutritional management of grazing animals

Effective nutritional management requires information on the quantities of feed the animals are grazing, the consequent supplies of energy and nutrients and efficiency of their use by the animals, the requirements for the desired level of production, what type and amount of supplement could minimize a discrepancy between supply and requirement, and whether the cost of the supplement would be less than the value of an increase in production. These matters were at the core of the work for a Report on Feeding Standards for Australian Livestock: Ruminants' (SCA, 1990) which now forms the basis of the GrazFeed program (Freer et al., 1997; Horizon Technology, PO Box 598 Roseville, NSW 2069, Australia) which is a widely used system for the nutritional management of grazing cattle and sheep. With continuing development of this program, a number of the recommendations of SCA (1990) have been further developed.

Many schemes for predicting feed intakes (e.g., Ingvartsen, 1994) depend on measures of animal production such as milk yield. This retrospective approach, the estimation of intake from production, is not satisfactory for effective nutritional management. It is necessary, as with GrazFeed, first to predict the quantity and quality of the intake and then, after allowing for the maintenance requirements of the animals, the resulting milk yields, rates of growth etc.

The scheme of Freer et al. (1997) predicts, without reference to actual animal production, the amount and quality of feed grazed by any given type of sheep or cattle from widely varying types of pasture, though not from semi-arid rangelands of mainly shrub vegetation. It requires estimation of the amounts of green and dead herbage present on the pasture being grazed, the mean digestibility of both categories, the mean pasture height, and the proportion of legume. This information is as important for viability in pastoral production as is knowledge of feed composition and nutritive value in intensive production systems, and it has been found that the ability to make these estimates can be acquired readily by farmers. Effects of selective grazing from the herbage available on the composition of the intake are accommodated, as are the effects of provision of supplementary feed. If there is a nutrient inadequacy in the herbage (e.g., low concentration of N or a mineral) the amount grazed will be increased by the consumption of an appropriate supplement, but if there is no inadequacy it will be reduced to an extent varying with the type of both the supplement and the pasture. Substitution rates, being the decrease in herbage dry matter intake (DMI) per kg of supplement DM eaten, will approach zero on very bare pastures but may be close to 1.0 when there is abundant herbage and both it and the supplement have high digestibility (DMD); rates in the middle of the 0 to 1.0 range occur when the DMD of the supplement exceeds the mean value for the herbage.

The array of nutrients required by grazing animals and their net requirements for growth, reproduction and lactation are the same as those of housed animals but the gross requirements for energy do differ because of the additional energy costs incurred at pasture (EGRAZE). The method for predicting these additional costs (SCA, 1990), to be added to the standard maintenance requirement (housed animals), has been adopted for beef cattle by the NRC (1996); it is based on calorimetric measurements made by Young and Corbett (1972) and in subsequent experiments.

$$\text{EGRAZE, MJ net energy/d} = [(C.DMI(0.9 - D)) + (0.05T/(GF + 3))]W$$

where:

C = 0.05 (sheep, goats) or 0.006 (cattle)
DMI = dry matter intake from pasture, kg/d, excluding supplement DM
D = digestibility of the DM (decimal)
T = 1.0 for level pasture increasing with increasing steepness to 2.0 (maximum)
GF = green forage on the pasture, expressed as tonnes DM/ha
W = animal liveweight, kg

The first term in the equation defines the additional NE cost to sheep or cattle of grazing their feed rather than eating it from a trough; it is related to the DMI and its digestibility. The values of the coefficient C imply that the relative rates of DMI (kg/h) from pasture by sheep and cattle are 1:8 respectively. No allowance is made for rumination because it can be expected that for any given quantity and quality (D) of feed intake the energy expended in this activity will not differ between grazing and housed animals. The second term defines the additional NE cost of walking; this increases with decreasing quantity of feed (GF) available because animals will have to forage over increasing distances, and it varies with the terrain (T).

The predicted ME requirements for maintenance of grazing animals, in the absence of cold stress, and like those obtained by experiment, indicate that these will not be more than 40% to 50% greater than for a similar housed animal, even in the most severe grazing conditions; in best conditions, with abundant highly digestible feed, the difference could be no more than 10%.

In the calculation of liveweight gains, at any given ME concentration in pasture herbage (M/D, MJ/kg DM) the predicted value for efficiency of ME use for growth and fattening (k_g) varies with time of year, and increases with increasing proportion of legume (figure 2). The variation with time of year stems from the finding that k_g for temperate pasture is greater with early (spring) growths than later growths of similar M/D (Corbett et al., 1966; Blaxter et al., 1971); it also appears to be sustained for a longer time with leguminous than with grassy herbage (Freer and Jones, 1984). There is also evidence (Corbett and Pickering, 1983; Dove and Milne, 1994) for seasonal variation in the yield of microbial crude protein (MCP, g/MJ fermentable ME; figure 2) which probably contributes to the corresponding variation in k_g. In both instances the higher values appear to reflect a chemical composition of the herbage, especially a relatively high water-soluble carbohydrate, that is associated with ruminal acetate: propionate ratios of 3:1 or narrower (Corbett, 1987) and is directly related to rumen propionate concentration (Dove and Milne, 1994). A similar seasonal variation in k_g and MCP yields has not been reported for tropical pastures. Consequently the equations to predict these (Freer et al., 1997) both include a term such that the values vary cyclically according to day of year, but with an amplitude that decreases with latitude towards zero at the equator.

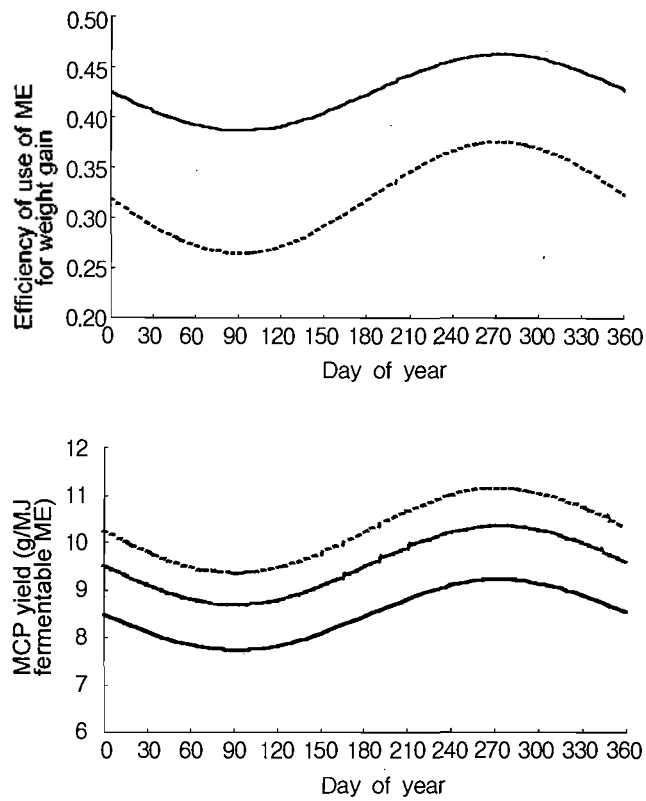

Figure 2. Predicted values, for pasture diets, for the efficiency of use metabolizable energy (ME) for weight gain (k_g), and for rumen microbial crude protein production (MCP, g/MJ fermentable ME). The variation with time of year is for latitude 35° with day 1=January 1 (southern hemisphere) or = July 1 (northern hemisphere), its extent decreasing towards zero at the equator.

Values for K_g are for a pasture diet containing 30% legume at ME concentrations (MJ/kg DM) of 11.0 (solid line) and 9.0 (broken line).

Values for MCP show effects of feeding level relative to maintenance (L=1). Bottom line, L=1; middle, L=2; top, L=3.

Reprinted from Freer et al. (1997) with permission from Elsvier Science.

Grazing systems and the environment

Quantitative assessments of the interrelations between grazing animals and their feed supply, as with GrazFeed, can be repeated at weekly or longer intervals to guide tactical nutritional management. To ensure sustainability and profitability it is necessary to identify the long term consequences of tactical decisions on animal and pasture management. This is the purpose of GrassGro (Moore et al., 1997), a decision support system (DSS) which is a dynamic soil-pasture-animal model driven by weather and incorporates GrazFeed. GrassGro in turn is part of the larger GrazPlan DSS (Donnelly et al., 1997) which is designed to represent a whole farm system where the complete biological model is directed by a flexible management structure, with the facility for optimization of the management. The structure of GrazPlan is shown in figure 3. Underlying the dynamic simulation models is a data-base, MetAccess, derived from archives of daily weather records. The records for a nominated area can be displayed in many ways, including actual values or long term averages, with SD, for daily, monthly or yearly data, and probabilities can be calculated from the historical weather records of the occurrence of particular events defined by the user, such as high rainfalls or low ambient temperatures.

The neo-natal survival of lambs is jeopardized if weather conditions promote high rates of heat loss. The Lamb Alive DSS uses the historical weather records for a given district to calculate a chill index. This gives a measure of how lethal the environment at any chosen time of year will be for new-born lambs and, with consequent predictions of mortality, enables farmers to make decisions on the best time to mate their ewes and on other aspects of management such as benefits from feeding the ewes to improve their condition or providing shelter during lambing.

Donnelly (1998) has led a symposium on sustainable grazing systems for temperate Australia which shows how DSS promote financial and ecological sustainability, and provide detailed information on water balances in the systems and efficiency of use of nutrients in their soils.

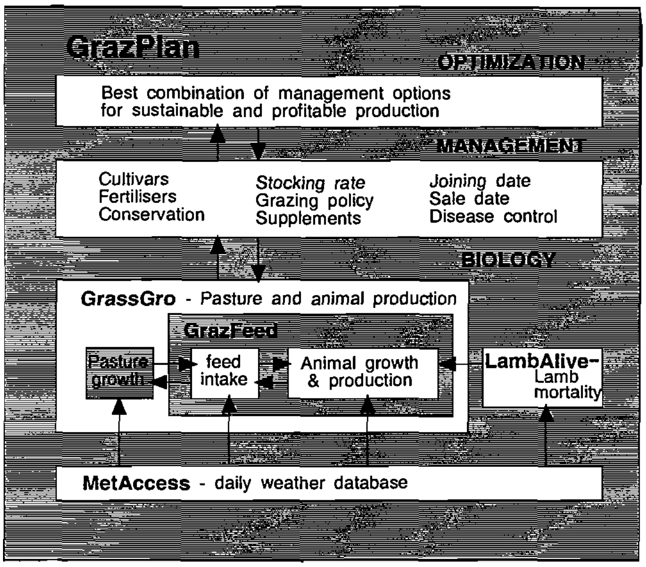

Figure 3. GrazPlan: Interrelations between its component biological models and decision support systems (see text) From Donnelly *et al.* (1997) with permission from Elsvier Science.

Effects of pastoral production enterprises can extend well beyond the areas of land that each directly employs. For example, loss of phosphorus in water runoff from pastures after rainstorms may adversely effect water quality in a very large catchment area, perhaps even promoting a major growth of blue-green algae (cyanobacteria) in an entire river system. This is one of the various effects that the enterprises can have on the environment. These effects and their consequences have been reviewed in detail by Williams and Hook (1998) and by Donaldson (1998), and include losses of soil organic matter and nutrients; acidification; salinisation; waterlogging; decline in soil structure and compaction leading to increased runoff; erosion (including aeolian losses of soil); increasing chemical residues (e.g., from fertilizers; excreta, including sewage effluent; herbicides; pesticides); invasion of undesirable plant species; and loss of biodiversity (e.g., clearing of natural vegetation and consequent loss of fauna habitats). Grazing management is sometimes unfairly blamed. Donaldson (1998) describes how superphosphate fertilizer use in a catchment area was thought to be responsible for the P implicated in eutrophication in a water storage dam; the actual source of the P was found to be apatite in subsoils that entered the watercourse feeding the dam because of stream bank erosion.

Methane produced during fermentation of fibrous material by ruminant animals is a contributor towards global greenhouse gas emissions, and because it has a much greater greenhouse effect than carbon dioxide the ruminant production is often cited as a target for greater control. Johnson et al., (1991) have estimated that the world's livestock population, domestic and feral but principally cattle, produce about 14% of all methane entering the atmosphere. It is estimated that greater amounts are produced by natural wetlands (21%) and rice fields (20%); other sources are fossil fuel energy production (14%), burning biomass (10%), and landfills (7%).

There are two important points with respect to production of methane gas by ruminants. The first is that the methane is derived from fermentation of fibrous material that has been produced by the photosynthetic fixation of large amounts of CO_2 carbon. For example, temperate improved pastures in Australia grazed at commercial stocking rates fix between 3.2 and 4.6 kg CO_2/m^2 per year (Vickery, 1972), greatly offsetting the methane production of the grazing livestock. The cycle of carbon dioxide and methane in which the ruminant animal plays a role does not generate greenhouse gases from fossil fuels in the same way as the combustion of coal and oil. Consequently it can be argued that the ruminant does not contribute *de novo* production of greenhouse gases. The second point is the efficiency with which ruminants produce meat or milk relative to the production of methane gas. In addition to measures of efficiency such as production per animal or production per unit area we should be increasingly aware of production per unit of methane. Animals growing slowly or losing weight on low quality fibrous feed are producing very high levels of methane per unit of production. On the other hand animals on high-quality diets, including from pastures, are likely to be far more efficient in terms of productivity per unit of methane because of an increased production of meat and milk per unit of feed consumed, and a reduced production of methane per unit of feed fermented. For example, the higher net energy value of a spring than of a later growth of herbage (Corbett et al., 1966) was associated with a lower methane production, 4.5 g CH4/MJ NE_g compared with 7.4 g/MJ NE_g from the later growth.

Intensive animal production

Efficient use of feed, as in pastoral production, is essential for profitability in the pig and poultry industries, feedlots, and other intensive animal industries. Efficient use will also result in minimum wastage of feed and, therefore, minimize potentially adverse effects on the environment. AusPig (Black et al., 1986; DSL Systems Centre, CSIRO Animal Production, Blacktown, NSW 2148) is a DSS used widely in Australia, and internationally. It predicts the energy and amino acid requirements for specified levels of performance by pigs in a variety of housing and climate conditions; it incorporates FeedMania (Saltbush Software, ABRI, University of New England, Armidale, NSW 2351) for optimal cost diet formulation. AusPig predicts carcass composition as well as growth, and includes a piggery profit-maximization model which determines the most profitable way of employing capital, labour, and pig-housing. CamDairy and CamBeef (Camden Animal Management Software, Cobbitty, NSW 2570), which incorporate much of SCA (1990), are applicable to both pasture-based and feedlot milk and beef production; these DSS calculate the most cost-effective supplements and rations, predict animal performance, and identify limiting nutrients.

Waste management in the animal industries

Pollution associated with mineral waste from intensive animal production is of concern because increased phosphorus, nitrogen and sodium in the surface and ground water lead to problems in managing water resources. This is an issue which needs management at the level of entire catchments and requires long term planning to be effective. Although relatively minor changes can be made in the nutritional management of animals under intensive production systems to reduce mineral waste production, the major means of controlling the problem is in siting the industries in appropriate locations and in managing waste containment in an appropriate way at each location. Odour nuisance also has to be controlled.

There are important differences between grazing and intensive systems of animal management in the amount of methane produced from manure. Under grazing conditions the manure is exposed to the air and dries relatively quickly and methane production is significantly less than in systems where the waste is held in lagoons, or builds up as a thick layer of manure and urine. These moist aerobic conditions promote efficient and continuous methane production. The production in lagoons can be turned to advantage if the methane can be captured and used as an energy source, but logistical problems combined with the expense limit the extent to which this opportunity is exploited.

CONCLUSION

As stated by Williams and Hook (1998), global markets require quality produce, and assurance that animal (and plant) products are free of chemical residues, free of disease, and produced in a manner that is benign to the environment. Great attention is being paid in Australia to a variety of Quality Assurance (QA) programs to satisfy, or exceed, ISO 9000. These programs, established and controlled by Government, Statutory and other authorities and agencies, include the Australia-wide Sustainable Grazing Systems Program and the Cattlecare QA for both grass fed and feedlot animals; they are steered and overseen regionally, and locally on individual farms. Beef producers, for example, are required to certify that all animals of any age that they sell, whether or not for slaughter, have not been treated with or exposed to a comprehensive list of veterinary and agricultural chemicals. Beef and all other food products are subject to detailed examination and analysis at the processing plants.

Australia exports a large proportion of its agricultural production (tables 1 and 3). It strives continually to sustain, substantiate and enhance its position as a supplier of 'clean and green' food of the highest quality.

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