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MATHMATICAL MODELS AND DECISION SUPPORT TOOLS FOR TECHNOLOGY TRANSFER TO THE LIVESTOCK INDUSTRIES – A SYMPOSIUM

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INTRODUCTION

Feeding systems (i.e., specification of feed requirements) for livestock were introduced some decades ago. Since their inception there have been ongoing efforts to improve their accuracy, increase their "ease of use" and extend their flexibility so that they can be applied with greater effect to a wider range of management questions. Attempts to increase the accuracy and flexibility of feeding systems have frequently led to an increase in their complexity. Initially this caused a dilemma since more complexity was considered to be at the expense of "ease of use", and in the days when there were no personal computers and few, if any, personal calculators, this was true. The availability of cheap, powerful desktop and laptop computers has removed this barrier to improving feeding systems. In fact, the "ease of use" of feeding systems, now in the form of Decision Support Tools based on mathematical models, has been greatly improved. In the twenty years or so since personal computers first became available researchers have been able to increase the comprehensiveness of the feeding systems and to extend their application from intensive feeding enterprises to grazing enterprises, and to address many complex management questions. This is illustrated by several Decision Support Tools, namely AUSPIG, GrazFeed and GrassGro, described in this paper. AUSPIG and GrazFeed, have now been successfully adopted by many managers of livestock enterprises. This appears to be a direct result of the fact that these tools are now easier to use than earlier versions of feeding systems, and because they are more comprehensive offering options that assist in achieving greater returns on investments. GrassGro is aimed at addressing a wide range of management questions that arise in grazing enterprises. In grazing enterprises, many of the questions that arise are strategic rather than tactical in nature placing greater demands on the models required. Although these Decision Support Tools are proving to be very successful, inevitably they do not address all the demands made on them and improvements and upgrades are still required. Therefore potential for improving the animal models on which these Decisions Support Tools are based is also discussed in this paper.

EXPERIENCES IN THE SUCCESSFUL ADOPTION OF AUSPIG BY INDUSTRY

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THE AUSPIG DECISION SUPPORT SYSTEM

AUSPIG is a Decision Support Software system developed for the pig industry. It predicts the growth of individual pigs from birth to maturity and the profitability of a whole enterprise. AUSPIG has four major components. The central module is based on the underlying physiological and biochemical mechanisms determining nutrient utilisation and simulates feed intake, digestion and absorption of individual nutrients and the partition of absorbed nutrients between various body functions to predict growth and body composition. The reproductive performance of breeding female pigs is predicted in relation to the genetic potential of the animal, its body tissue reserves and nutrient intake. The number of piglets born, birth weight, milk yield and piglet growth rate are predicted. The model accounts for the effects of social interactions between animals, climate and disease, and predicts the requirements for individual amino acids, energy and major minerals in relation to the genotype of the pig, its weight and reproductive state. The model is deterministic and predicts the performance of one pig, which represents the mean of the group being simulated. Stochastic variation is applied only to variables, which determine the price paid for the animal including carcass weight and back-fat thickness.

The second component of AUSPIG is a least-cost feed formulation package and feed ingredient database. The interface between the animal module and the feed formulation module allows the most economical diet to be formulated for a pig of any age or weight reared in any environment. The third module is a whole enterprise linear program which accepts outputs from the animal module and optimises the use of all resources, including growing animals, feed, space and reproductive stock, to maximise enterprise profitability. This module is particularly important for identifying the optimum weight and the buyer for purchasing each group of pigs and for determining the effect on enterprise profitability of changing any management strategy. The final module is an Expert System that assists the user of the program identify the management changes that will lead to the greatest increases in biological efficiency and enterprise profitability.

DEVELOPMENT AND COMMERCIALISATION OF AUSPIG

The pig growth and production model at the core of the AUSPIG system was initiated in response to a request from the Pig Sub-committee of the Animal Production Committee on direction from the Standing Committee on Agriculture to implement uniform feeding standards for livestock across Australia (Robards and Radcliff 1987). The model was to embrace all major nutritional, physiological and environmental factors, which influence the growth and body composition of pigs. It was developed in 1985 during a time of rapid change in the genetic background of Australian pigs when the relationships between the intakes of energy and amino acids, and body protein and fat gains, and consequently, nutrient requirements were changing rapidly. The Sub-committee recognised that Tables of requirements were too inflexible to allow for these changes and that a simulation model based on the underlying mechanisms of growth was the only realistic method of assessing the nutrient requirements of pigs with rapidly changing genetic backgrounds and exposed to different environments. The last set of tables produced in Australia for the nutrient requirements of pigs was generated from the model (Robards and Radcliff 1987). Since then, the AUSPIG system has become Australia's primary method for determining the nutrient requirements of pigs. The model was expanded during 1986 to 1988 to include the other AUSPIG modules, which allow the direct formulation of diets for pigs raised in specific conditions, enable evaluation of the economic consequences of changes in management strategies on enterprise profitability and to make it readily useable by industry professionals.

AUSPIG was released commercially in 1989 and is now used in the management of more than half of Australia's pigs (Quint and Treacy, 1997). AUSPIG was also licensed in 1989 for a multi-million dollar sum to a major international feed manufacturing and pig rearing company and the licence has been maintained until the present day. There are numerous examples of the way AUSPIG has improved the profitability of individual enterprises and changed common management practices in several countries of the world (Black *et al*. 1987, Black and Barron 1988, Black and Chapple 1991, Bradley 1994, Brewster 1995, de Lange and Schreurs 1995, Edwards 1997, Smits 1997, Black 1998, Willis 1998, McErlane 2001, Willis 2001a, Willis 2001b). In addition, AUSPIG has been used extensively to determine the directions of research within the pig industry (Cutler and Gardner 1988, Black *et al*. 1994).

EXAMPLES OF THE APPLICATION OF AUSPIG

Optimisation of biological efficiency and profitability

A common application of AUSPIG has been identification of the factors limiting biological efficiency for growth and evaluating the effects of changes in management procedures that are likely to improve profitability (Black and Barron 1988, de Lange and Schreurs 1995, McErlane 2001, Willis 2001a,b). The first step in the process is to obtain accurate information from the farm including a description of the genotype and sex of animals, the ingredients of the diets fed, the feeding strategies, the climatic environment and the stocking and housing arrangements for each class of pigs. An indication of the prevalence of disease in each class of animals also is required. Actual pig performance information is recorded, including the growth rate of individual pig classes, feed disappearance, slaughter weights and back-fat thickness at slaughter. The information collected is incorporated into a data set within AUSPIG and used to describe the conditions for simulating pig performance on the farm. The predicted growth rate, body fat content as indicated by P2 back-fat thickness and ratio of feed disappearance to live weight gain (feed:gain) is then compared with the values obtained from the farm. It is essential that the observed and predicted values for animal performance correspond before the model can be used effectively to identify biological inefficiencies and recommend changes in management practices to improve profitability. The Expert System is used to help identify possible errors in data input.

Once piggery performance has been simulated accurately, the Expert System is then used to identify factors limiting biological efficiency. These factors are considered in a specific order so that changes are recommended first for feed intake and diet composition before those for climatic conditions or stocking arrangements. The order of consideration is important because any alteration in either feed intake or diet composition will change the heat produced by the pig and will therefore alter the ambient temperatures coincident with the thermoneutral zone when the pig is neither hot nor cold. Stocking arrangements are considered last because feed intake, diet composition and climatic conditions all affect growth rate which will impact on the time that pigs within a pen may be either under- or over-stocked. The model identifies the factor limiting feed intake when the pigs are fed *ad libitum* and determines the extent to which individual essential amino acids and available nitrogen are either deficient or in excess of requirement. If the pigs are cold, the additional amount of radiant heat required to bring them into the thermoneutral zone is predicted and if they are hot the advantages of spray cooling are assessed.

The Expert System recommends changes in marketing and management strategies that will improve profitability of the enterprise and biological efficiency for each class of pig. It identifies the optimum sale weight from the price grids of up to three processors and may recommend changes in either sale weight or processor to improve profit. Frequently, in Australia, a substantial increase in profit results simply from a change in sale weight and/or market outlet.

The earliest example of an AUSPIG application was for a 275 sow enterprise in the Darling Downs in Queensland (Black and Barron 1988). The growth rate of the pigs from birth to slaughter was only around 460 g/d, whereas a growth rate of over 600 g/d should have been expected. The AUSPIG simulation suggested that several factors were limiting pig growth rate and enterprise profitability. All three diets offered to the pigs were predicted to be limiting in the supply of several amino acids, particularly threonine and lysine, which resulted in a reduction in growth rate and production of over-fat pig carcases. In addition, the pigs were predicted to be hot during the summer months and feed intake was severely restricted over this period. The diets were reformulated to contain adequate amino acids and spray cooling was introduced. The pigs then grew faster at a rate of approximately 580 g/d, but because of their faster growth rate they were then overstocked, which limited feed intake. Although an increase in area/pig was predicted to increase growth rate to 608 g/d, the reduction in total throughput of pigs as a consequence of the extra space needed for each pig was predicted to reduce overall enterprise profitability. Application of the whole enterprise profitability module suggested that the observed herd feed conversion ratio (kg feed/kg carcase) of 4.4 could not be achieved unless feed wastage was 15-20%. As a result of these predictions the producer and his staff discovered that one group of 400 pigs was receiving 30% more feed than they could possibly consume. The feeding regime was changed from twice to four times daily with a visible reduction in feed wastage. Introduction of the changes suggested from the AUSPIG simulations were predicted to result in a four-fold increase in enterprise profitability.

Other examples of the application of AUSPIG to individual herds have recorded increases in profitability of 7-10% simply by formulating diets to fit closely the change in amino acid requirements as the pigs grow (Brewster 1995, de Lange and Schreurs 1995, McErlane 2001). A recent evaluation of a large production unit by Willis (2001b) showed that performance of the pigs was limited by cold conditions and inadequate amino acid supply in the early phases of growth and by amino acid excess and over-stocking during the finisher phase. de Lange and Schreurs (1995) showed also that the traditional method of restricting feed intake on Dutch farms to limit fat deposition was not optimal and that by increasing intake in the young pig and reducing it more severely in the finisher pig, profitability could be increased by over 30%. This application of AUSPIG has changed the traditional feeding strategies used in The Netherlands.

Optimal use of dietary protein and free amino acids to reduce nitrogen loss in effluent

The disposal of effluent from intensive livestock enterprises is becoming a major concern for environmental monitoring agencies. Piggeries in many countries are either now or are soon likely to be licensed for maximum rates of nitrogen and phosphorus release. AUSPIG has been used to determine the consequences of reducing the protein content of the diet and improving the balance of amino acids within the protein on pig performance, profitability and nitrogen output in effluent (Pluske *et al*. 1997). The predicted effects on total nitrogen excretion in urine and faeces of limiting total available nitrogen content of the diet to 120% of requirement for pigs growing from 50 to 100 kg and formulating the new diet every 10 kg is shown in Table 1. The strategy was predicted to reduce nitrogen output by 66% compared with the conventional diet with only a small decline in profitability due to the need to include several expensive free amino acids in the diet. Nevertheless, the overall profitability of the piggery may increase depending on the costs associated with effluent disposal.

Table 1. Predicted N excretion and profitability for pigs grown from 50-100 kg live weight when offered a range of diets differing in protein and amino acid balance. From Pluske *et al.* (1997).

	Standard	Phase-1[a]
Dietary protein %		
Diet 1	21.8	15.3
Diet 2		15.0
Diet 3		14.5
Diet 4		13.5
Diet 5		11.8
Feed cost ($/pig)	35.23	37.91
Change in profit ($/pig)	0	-2.70
Total N intake (g/d)	73.7	45.2
Total N excretion (g/d)	51.4	22.8
N excretion as % of standard	100	44

[a] Phase-1 diets were formulated with a maximum limit on total available N set at 120% of requirement and new diets formulated and fed to pigs for every 10 kg live weight.

Effect of the digestible energy content of cereal grain on piggery profitability

The digestible energy content of cereal grains grown in Australia can vary by as much 3 MJ/kg for the same species depending on the cultivar and growing conditions (van Barneveld 1999). Kopinski (1997) has used AUSPIG to assess the consequences of a difference in digestible energy content of wheat grain of only 0.7 MJ/kg on the profitability of a 200 sow herd in Queensland. Table 2 shows the predicted effect on piggery profit of this 5% reduction in the digestible energy content of wheat assuming the diet was formulated without knowledge of the reduction. Such a situation would commonly occur in practice because of the lack of reliable and rapid methods for estimating the digestible energy value of grains for pigs. The lower digestible energy content of the cereal grain in the diets was predicted to result in no change in the growth performance of the pigs from birth to slaughter but a significant increase in the amount of feed eaten. Over the whole growth period an extra 70 g more feed was predicted to be used for every 1 kg of live weight gain. The increase in feed eaten resulted in a reduction in profit of $1.95/pig sold and this translated to a lowering of over $7,500 in the annual profit of the piggery.

Table 2. A comparison of pig performance and financial returns when the actual digestible energy (DE) content of wheat is either equal to or 5% less than the value used to formulate the diets for the piggery. (From Kopinski 1997).

Variable	Actual DE equals formulated DE	Actual DE is 5% less than formulated DE
Assumed DE of wheat at formulation (Mcal/kg)	3.42	3.42
Actual DE of wheat (Mcal/kg)	3.42	3.25
Wheat cost ($/tonne)	190	190
Live weight gain from birth (g/d)	555	555
Feed:gain from birth	2.62	2.69
Profit ($/pig)	9.66	7.71
Profit ($/sow/y)	187	149
Profit for 200 sow piggery ($/y)	37,386	29,818

Cost of feed wastage

Results from Hudson (1998) show that feed wastage can range from 2.5 to 40% of the feed offered to pigs depending on the physical form of the feed and the type and adjustment of the feeder. AUSPIG was used to assess the effect of feed wastage on the profitability of the 200 sow reference herd (Table 3). Feed waste was altered only in the grower herd and was assumed to be unaltered for breeding sows and boars. Feed wastage was changed from 0 to 15% of feed intake, but actual feed intake and performance were assumed to be unaffected by feed wastage.

Table 3. Predicted effect of feed wastage on profitability of a 200 sow piggery.

Feed Waste (%)	Feed Costs ($/y)	Profit ($/y)	Total feed (t/y)	Feed/sow/year (t)
0	348,373	204,022	1,109.5	5.545
4	358,427	193,827	1,141.3	5.705
8	368,672	183,724	1,172.9	5.865
12	378,867	173,529	1,204.7	6.024
15	386,409	165,987	1,228.3	6.142

The annual income and non-feed costs were unaffected by feed wastage and predicted to be $789,161 and $236,765, respectively. Profitability of the 200 sow reference piggery was shown to increase by $2,548 for every 1% decline in feed wastage. This represents $12.70/sow/year for each 1% of feed intake wasted. Commonly, values for feed waste of between 10 and 15% are required in AUSPIG to predict observed herd feed conversion ratios when simulating Australian piggeries. However, in one recent example, feed wastage of almost 40% was required to simulate accurately feed usage by the whole herd. In the above example, such a feed waste would cost the reference piggery over $100,000/year and reduce profit to 33% of the value if feed waste was controlled to only 4% of feed intake.

Carcass price needed when pigs are sold at sub-optimal weights

As another example of the way AUSPIG can help improve profitability of farms, it was used to determine the price that would be needed by a producer if the processor requests pigs at lighter weights than is optimal under the current selling system. The example used a standard buyers price matrix in which the price/kg carcase varies with carcass weight and back-fat thickness. For the particular example, profit was maximised when 10% of pigs were sold at a carcase weight of 70kg, 75% at 75kg and 15% at 80kg. The predicted effect on price required per kg carcase, if profit was to remain unchanged, of selling all carcases at either 50 or 60kg was determined under two circumstances; (i) assuming that the number of sows could not be increased or (ii) assuming that total floor space was limiting but could be redistributed between different stock classes (Table 4).

Table 4. Predicted effect of selling pigs at sub-optimal weights on annual profit relative to optimal selling weights and on the price needed/kg carcass to restore profit.

Simulation	Relative number of sows	Relative profit	Relative number of pigs sold	Relative loss (% profit)	Loss ($/pig sold)	Price increase needed to restore profit ($/kg carcase)
Normal optimal selling	100	100	100	-	-	-
50 kg carcasses						
Sows limited	100	32	101	68	35.69	0.71
Floor space limited	131	53	132	47	18.14	0.36
60 kg carcasses						
Sows limited	100	64	100	36	18.80	0.31
Floor space limited	116	81	116	19	8.82	0.15

The simulation shows that the price would have to be increased above the current price schedule by between 0.15 and 0.71 $/kg carcass if the profit from the piggery were to be maintained. Such information is essential for both processors and producers if acceptable price matrices are to be negotiated.

Identifying specific amino acid deficiencies

Although most commercial feed formulation packages have the scope to include many hundred nutrients, feed formulators often consider a relatively small number, particularly when many diets are being optimised concurrently. However, there are dangers in this practice. Table 5 gives an example where only 5 amino acids (lysine, methionine, methionine + cystine, threonine and isoleucine) were considered during formulation of a diet for pigs growing from 42 to 63 days of age. The conditions of the trial also were used as inputs to the AUSPIG model. Predicted growth rate and feed intake compared closely with the observations. The AUSPIG model predicted that valine and leucine were limiting the performance of the pigs. Further simulations were conducted where free valine and leucine were added to the diet and growth rate of the pigs was predicted to increase by 16%. A subsequent experiment has confirmed that, when the diet formulated to meet the requirements of only 5 amino acids was supplemented with increasing amounts of valine, growth rate and the efficiency of feed use increased up to valine intakes coincident with the requirement predicted by AUSPIG.

Table 5. Observed growth rate and feed intake of pigs offered a formulated diet to meet the requirements of only 5 amino acids (lysine, methionine, methionine + cystine, threonine and isoleucine) from 42 to 63 days of age compared with predictions from the AUSPIG model.

	Observations	AUSPIG Predictions		
	Formulated diet	Formulated diet		Diet + Val & Leu
Growth rate (g/day)	650	638		741
Feed intake (g/day)	949	952		955
		% Requirement at day 63 of age		
		Valine	Leucine	
		87.5	89.9	

Other applications of AUSPIG

There are a large number of other applications for which AUSPIG has been used include:

- Designing new piggeries to meet growth rate and production targets
- Assessing the economic value of new products such as Reporcin and Improvac that alter growth and body composition
- Assessing the cost or advantage of skipping an oestrous cycle when mating sows
- Assessing the benefits of reducing embryo mortality or pre-weaning mortality on piggery profitability
- Assessing the cost of introducing Transmissible Gastro-Enteritis into Australia
- Assessing the costs of the introduction of a range of diseases into piggeries
- Identification of new selection strategies for pigs
- Litigation cases involving diets and management recommendations

This list is not exhaustive and many “what if” questions are amenable to analysis using AUSPIG.

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GRAZFEED - A DS TOOL FOR MANAGING THE NUTRITION OF GRAZING ANIMALS

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OUTLINE OF GRAZFEED

GrazFeed is a decision support tool (DS tool) that is in widespread use by farmers and farm advisers to increase profits from sheep and cattle livestock enterprises through efficient use of pasture and feed supplements. The user estimates the amount and quality of green and dead herbage available for grazing, including the proportion of legume if it is present. The mature size and physiological status of the animals grazing the pasture are also entered. GrazFeed then predicts their intake of pasture, making allowance for selective grazing and the substitution of pasture by any supplements fed. It estimates the production of meat, wool and milk and provides details of the nutrient balance of the animals. If the predicted production is below the user's target, the program will estimate the weight of a supplement required to achieve this level.

OUTLINE OF ANIMAL MODEL

The animal model used in GrazFeed is based on equations (Freer *et al*. 1997) of biological processes that, in many cases, are common to sheep and cattle. Specific coefficients derived from feeding standards (SCA 1990) are used to differentiate common breed types at all stages of their growth and reproduction cycles. Scaling feed intake, body composition, wool growth and milk production to the mature size of the particular type of animal being simulated, rather than to its current weight, is a key component of the generality of the model. The model predicts the intake of metabolizable energy and protein from the pasture and supplements described by the user and these intakes are partitioned between maintenance and the competing components of animal production.

This approach has proved to be sufficiently realistic and simple for routine use in advisory work (see Stuth *et al*. 1999) and particularly to set production benchmarks in the national PROGRAZE extension project (Bell and Allan 2000). However, if the purpose is to tailor feed composition to achieve a specific carcase conformation such as that required by feedlot operators, more explicit simulation of the processes involved in animal tissue metabolism will be required, as described later in this contract by Nagorcka.

RELEASE STRATEGY

GrazFeed was first released for commercial use in 1990 and subsequently more than 1200 licences for its use have been issued. At that time, it reflected the current understanding of ruminant nutrition, as expressed in the feeding standards, but constrained by the type of information that typical users on farms could reasonably supply. The generic basis of the tool made it immediately applicable to a very wide range of issues relating to practical issues in ruminant nutrition, but it also meant that it was not feasible to test in any comprehensive way the plausibility of all the specific outcomes that might be predicted by the model. The initial release was with the expectation, therefore, that users would report suspected deficiencies and that this feedback, together with more recent experimental information, would be the basis for future enhancements of the tool. GrazFeed has subsequently undergone numerous upgrades as part of this deliberate policy.

USING GRAZFEED

GrazFeed provides an easy way for livestock producers to use the recommended feeding standards, without direct involvement in the complex and time-consuming calculations needed to predict pasture intake and relate nutrient requirements to feed supply. However, the predictions depend on accurate key information about the pasture and the animals from the user. Although these requirements are kept as simple as possible, they represent a hurdle to the untrained user.

The user describes the pasture by the weight (tonnes DM/ha) and dry matter digestibility of the green and dead herbage separately and by the proportion of legume in the pasture. From this information, the program develops a profile of the pasture's distribution between six digestibility pools, and of the crude protein content and the mean height of the green and dead herbage. All of these values, which affect the functions for predicting selective grazing and the proportion of the animal's potential intake that can be satisfied by the pasture, can be adjusted by the user, if necessary.

The ability of users to make a quantitative assessment of a particular pasture has been widely extended by the PROGRAZE training courses (Bell and Allan 2000). This ability must be reinforced by regular calibration of weight and digestibility estimates made either by visual estimation or by electronic probe. Moreover, the calibration of herbage weight must use the standard cutting technique for which the model's functions were scaled.

The key animal input is the weight (shorn) of a mature non-pregnant female in average condition, i.e. a condition score in the middle of the range. From this, the program estimates the mature weights of castrate and entire males of the same genotype. Many of the functions in the program depend on the mature weight, the proportion of this weight that the immature animal has so far reached, or on the animal's current weight as a proportion of mature weight, i.e. relative condition.

The user also specifies the supplement mix that is being used, or is to be tested. The program is then set to run, either with a number of levels of the supplement or to predict the weight of the supplement that would be needed to achieve a specified weight gain, milk yield or weight gain of suckled young. These simple predictions can be expanded through plotting routines that illustrate the effects of interacting variables, e.g. the quality of the supplement or the amount or quality of green herbage, on the predicted outcomes.

The basic tabulation of the output is accompanied by a set of comments that are tailored to the particular run and are designed to direct the user to the main constraint to animal production, e.g. low availability or quality of pasture, shortage of either degraded or undegraded protein.

GRAZFEED APPLICATION

In the example shown in Table 1, Merino ewe weaners graze abundant but dead summer pasture with a low concentration of crude protein. In the absence of a supplement, intake of herbage was restricted by a deficiency of rumen degradable protein and liveweight loss was severe. Supplementation with oats alone (10% crude protein) does little to rectify the protein deficiency; herbage intake is further depressed and the effect on weight change was only moderate. On the other hand, as little as 100g of a 60:40 mixture of oats and lupins (18.5% crude protein) corrects the protein deficiency, maintains the intake of herbage and brings the weaners close to the point of weight maintenance. If a target weight gain of 50 g/d is set, then the program predicts that 380 g of the mixture would be required. To achieve the same target with oats alone would require 520 g, an amount that would be quite likely to lead to feeding problems in animals of this size. Larger gains, of the order required for finishing weaners as prime lambs, would be impossible to achieve with this supplement. These predictions are very similar to the experimental results of Freer *et al.* (1985).

ADOPTION OF GRAZFEED

The concurrent development of the Australian feeding standards and the animal model used in GrazFeed had a significant impact on gaining acceptance of the tool as a useful approach to managing the nutrition of grazing animals. This and the signing of a formal agreement between CSIRO Plant Industry and NSW Agriculture for the development of the GRAZPLAN software packages (Donnelly *et al*. 1997) by CSIRO and their use in the livestock advisory service, underpinned their broad acceptance within NSW Agriculture. Such agreement was not sought with extension organizations in other States and a similar level of acceptance has been slower to achieve.

Table 1. Predicted response by 6 month, 22 kg ewe weaners of medium Merino type, grazing abundant dead pasture (2 t/ha DM, DM digestibility 44%, CP 3% of DM), to supplementation with either oats alone (CP 10% of DM) or a 60:40 mixture of oats and lupins (CP 32% of DM).

	Oats alone			Oats and lupins (60:40)		
Supplement intake (g)	Pasture intake (g DM)	CP in diet (%)	Weight gain (g/d)	Pasture intake (g DM)	CP in diet (%)	Weight gain (g/d)
0	420	6	-81			
100	400	6	-31	480	8	-11
200	360	7	-1	500	9	15
400	280	8	30	470	11	54

Nevertheless, the link with the feeding standards has been vital in the longer run. It means that disagreements with the predictions can be separated into issues that are the direct province of the feeding standards and those that are to do with estimating intake. Although the latter are mostly issues that can be solved by reaching agreement with users on standard procedures for assessing pastures and animals, even such simple standardization remains an obstacle to the consistent interpretation of information generated by GrazFeed.

A major advance in developing these assessment skills has been achieved by the PROGRAZE Project (Bell and Allan 2000) which has already trained several thousand graziers in southern Australia. Before 1994, sales of GrazFeed to graziers were less than 15% of the total sales; since PROGRAZE started, this figure has jumped to more than 50%.

IMPROVEMENTS NEEDED IN THE ANIMAL MODEL

The current feeding standards recognize that there are several areas of ruminant nutrition that are still too poorly understood to quantify adequately the relationships between feed composition and grazing animal productivity. Worthwhile improvements to the animal model will come, in particular, from better data for the prediction of intake from different pasture species, substitution rates for supplements, synchronization of nutrient supply to the rumen microbes and the partition of nutrients in animals with low levels of intake relative to their needs. There are also many aspects of product quality, e.g. staple strength of wool, meat quality, milk composition, where the understanding of the mechanisms is still at the experimental stage.

FUTURE EXTENSIONS

The initial releases of GrazFeed were suitable for most of the breeds of sheep and beef cattle used in Australian grazing enterprises. The adequacy of GrazFeed for high-yielding dairy cows under intensive grazing has recently been tested with experimental data from Kyabram Dairy Centre. Modifications to the program have improved the predictions, particularly for the cows' responses to variable herbage allowances at different levels of supplementation.

The next release of GrazFeed is expected to include a least-cost ration formulator to enable graziers to select the most efficient supplement mix from a menu of feeds likely to be available to them. The development of this facility is more complicated than for stall-fed animals because of the change in substitution rate that occurs with each change in supplement combination.

GrazFeed is a static model designed to help with tactical problems and provides merely a snapshot of the production possible on any one day, given the current condition of the animals, the availability and quality of feed on offer and the supplements that may also be provided. The predictions are limited where the product depends on the animal's earlier nutritional history, e.g. milk production, or where there is a lag between current nutrition and the measured product, e.g. wool growth and fibre diameter. Overcoming these problems requires the dynamic modelling capability achieved with the same animal model incorporated into GrassGro, the DS tool described in the next paper in this contract.

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GRASSGRO - SUPPORTING MANAGEMENT OF GRAZING ENTERPRISES FOR PROFIT AND SUSTAINABILITY.

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Managing a grazing enterprise is a difficult task given the complex biology that underpins production, the highly variable climate in which Australian graziers must operate, and the problems that large swings in commodity prices cause for business management. Lean *et al.* (1997) illustrated the difficulty of this task by contrasting the good fortunes of woolgrowers who focused on managing the "profit drivers" of their businesses (eg. enterprise type, stocking rate, time of lambing/calving, fertiliser management, feed supplementation policy, stock health, stock genotype), with the majority of growers who managed their farms without this focus. One characteristic of the latter group was to react to difficult times by cost cutting. This led to less investment in fertiliser, for instance, and locked the enterprises into a downward spiral in production and profitability. The outcome was quite the opposite of what was intended.

Although leading graziers have shown that maintaining a focus on business profit drivers is crucial (Burbidge 1996; Daniels 2000; Webb Ware 2000), it is still often difficult to make optimal decisions because of the biological and environmental complexity of grazing systems. Computer-based decision support tools such as GrassGro provide a unique way of coping with this complexity. GrassGro simulates the "grazing system". The interactions that occur between soil fertility, stocking rate and fibre diameter, or lambing time, stocking rate and supplementation policy, etc., can be seen readily and some of the risks associated with alternative management options can be quantified.

HOW DOES GRASSGRO WORK?

GrassGro was developed using knowledge gained from many years of agronomic and animal production research. It addresses management of sheep and beef enterprises and enables simulation of pasture and animal production, and some of the environmental processes, in temperate areas of southern Australia (Moore *et al.* 1997). The tool links models of soil, pasture and livestock to a climate database and, consequently, it is a computer-based representation of the environmental resources available to a grazier (see Figure 1). The pasture model is driven by the historical daily weather records of the Australian Bureau of Meteorology. In this way, the variability of climate and its consequences for production risk are revealed.

WORKING WITH GRASSGRO: WOOL PRODUCTION AT BOOKHAM, NSW

Graham and Hazell (1999) reported a decision-making dilemma faced by fine woolgrowers using unfertilised pastures at Bookham, NSW. The growers were locked into low stocking rates and low profitability because of a perception that using fertiliser did not pay. Experience had shown that superphosphate applications led to increased wool fibre diameter and poorer wool prices.

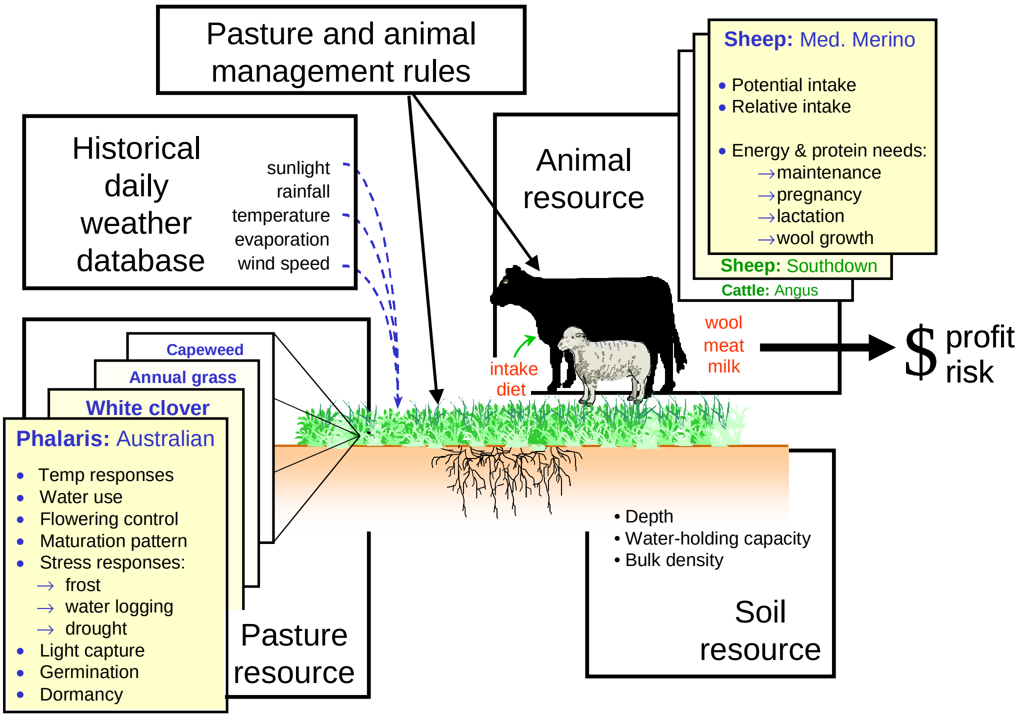

Figure 1. The environmental resources available to graziers as represented in the computer-based, GrassGro decision support tool. The weather data drive pasture and animal production according to the constraints imposed by the soil, pasture species, animal enterprise and the management rules specified by the user. The soil profile in GrassGro can be likened to a bucket that captures and holds rainfall for pasture growth. Key elements are soil fertility, the depth of soil that plant roots explore and the water-holding capacity of this zone. The GrassGro user selects pasture species to represent the pastures on the farm and in this way captures their attributes in the analysis of the grazing system. Each "pasture species" in GrassGro is a mathematical description of the plant's genotype, and it responds to the simulated environment to produce a phenotype that is appropriate for the farm location. The animal model used in GrazFeed is also used in GrassGro. Simulations readily demonstrate how well a grazing enterprise is matched to the farm environment and its pasture resources. Production is usually simulated over a number of years. This allows environmental, production and business risks that are associated with climate variability to be quantified.

The group have conducted a grazing demonstration since 1993 that proved that the results of research conducted elsewhere could be applied in their district. The outcome was a substantial improvement in profitability per hectare because superphosphate was used to lift stocking rate and this in turn helped the graziers to manage the fibre diameter of wool. However, the grazing demonstration did not answer many other important questions. Was the stocking rate of 12-15 wethers/ha that was achieved on fertilised pasture a sustainable target? Was it an achievable target for other farms in the district?

GrassGro gives graziers the opportunity to examine production problems without resort to an expensive grazing trial and it is now being used at Bookham to explore the additional questions that could not be answered by the grazing demonstration. GrassGro was set up to simulate management of the demonstration trial using local weather data (1965-1998), an appropriate Merino bloodline, appropriate soil fertility and soil profile descriptions based on soil samples collected in the grazing demonstration paddock and from paddocks on other farms in the district. Simulations of annual grass-subterranean clover pasture were conducted to examine the impact of differing stocking rates. Various aspects of the production system (e.g. supplementary feeding, pasture cover, animal condition, etc) can be used as decision criteria. Gross margin and business risk criteria are used in Figure 2 to determine an optimal stocking rate.

Simulation of the grazing demonstration site ("Kia-Ora") revealed that median gross margin increases as stocking rate is increased, but income variability (business risk) also becomes larger. In this analysis, the business risk is mostly associated with extra supplementary feeding in poor years and increased micron in good seasons. At "Kia-Ora", risk increased disproportionately at stocking rates above 12 wethers/ha. A disproportionate increase in risk is one criterion that may influence a stocking rate decision. However, selection of a preferred stocking rate also depends on the trade-off between profit and risk that is acceptable to each wool producer. The simulated paddock at "Talmo" differs from that at "Kia-Ora", only in the hydraulic properties of the root zone but this has a substantial

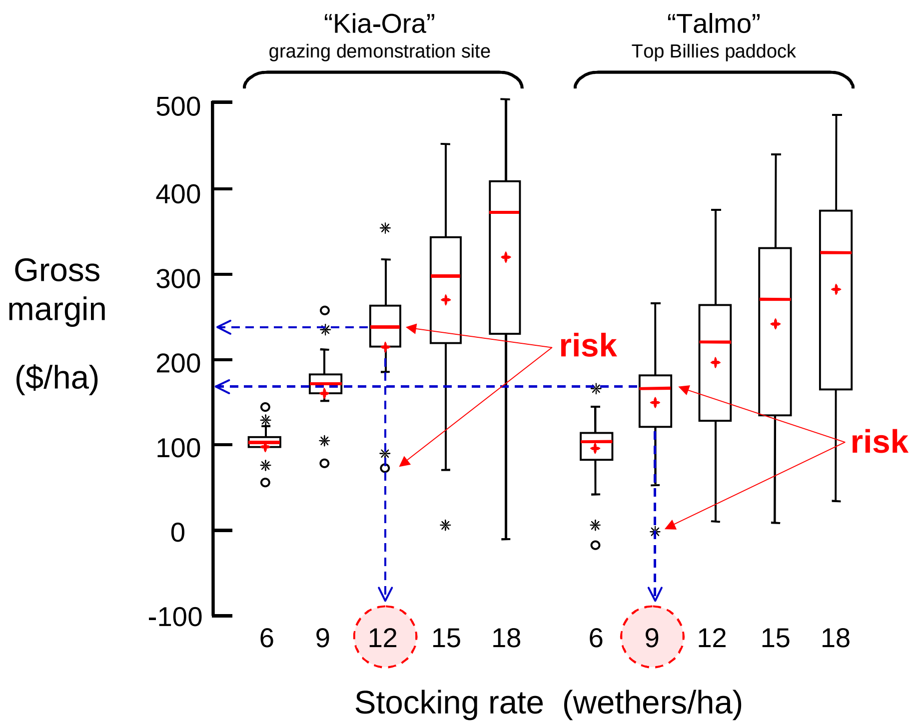

Figure 2. Distribution of annual gross margins for simulations based on weather data from 1965-98 using stocking rates of 6-18 wethers/ha at "Kia-Ora" and "Talmo" via Bookham, NSW, using wool prices current at September 2001. The middle horizontal bar in each box is the median value, the cross is the mean, the interquartile range is defined by the upper and lower edges of the box, the whiskers represent values less than 1.5 times the interquartile range. Outliers are represented by an asterisk and extreme outliers are represented by an open circle.

impact on the profitability and risk profile for this paddock. The "Talmo" paddock incurs higher business risk at all stocking rates and may require management at a lower stocking rate than was achieved in the grazing demonstration.

FARMING TO LAND CAPABILITY

GrassGro provides us with a comprehensive way to assess the capability of grazing land because it simulates the major environmental resources of the grazing system. Although the decision support tool encourages the user to focus on managing the profit drivers of grazing enterprises, some of the risks incurred by exceeding sustainable production levels are also exposed. Consequently, GrassGro has indicated potential to increase stocking rate in some cases (Behrendt *et al.* 2000), and has indicated a need to moderate stocking rate targets in others (Simpson *et al.* 2001a). In one case, an unforeseen soil nutrient deficiency was exposed when potential production was predicted to be substantially higher than was being achieved (Simpson *et al.* 2001c).

GrassGro has also been used to quantify the impact of location and management on drainage under pasture systems (Simpson *et al.*, 1998), to quantify exceptional drought circumstances (Donnelly *et al.* 1998) and to predict conditions conducive to mouse plagues (Pech *et al.* 1999). Indeed, the potential of the tool for assisting environmental management is only just beginning to be realised with the development of prototype versions of GrassGro that simulate nutrient cycling (Simpson *et al.* 2001b) and acidification of soil under grazing systems (Braschkat *et al.* 2001).

CURRENT ISSUES FOR ADOPTION AND FURTHER DEVELOPMENT OF GRASSGRO

GrassGro was released for commercial use in 1997 and presently in excess of 100 advisors have been trained to use it. By the time it was released many of the basic issues of whether computer-based tools would find a place in agriculture were well behind us. The success of GrazFeed had also paved the way for a grazing systems tool because many GrazFeed users were already demanding answers to grazing enterprise questions that GrazFeed was not designed to evaluate. Nevertheless, there are a number of significant issues for adoption and development of GrassGro.

(1) GrassGro is a comprehensive tool dealing with the major resources of a grazing enterprise. It is important that users have a clear understanding of the assumptions underlying the models and the limitations of the analyses. Consequently, GrassGro is only available to users who agree to undertake a training course.

(2) Quantitative information is needed to define the state of the resources when initialising the models in GrassGro. Graziers and their advisors already have a huge breadth of knowledge which they use when managing their grazing businesses, but in practice it is often a challenge for them to quantify that knowledge (e.g. what is the weight of a mature female of your bloodline in score 3 condition; what percentage moisture defines the wilting point of your topsoil?), and there is a substantial, initial learning curve. At the moment this issue is being addressed by encouraging primary adoption of GrassGro by advisors as they are more likely to be able to access quantitative information and can use it to benefit a number of grazier clients. GrassGro is also now an important component of some rural tertiary degrees (Scott *et al.* 2001) and this will ensure that new users are trained, have a systems perspective and will know how to readily access quantitative information.

(3) At the moment, the hydraulic properties of many soils are not known and the cost of the necessary soil tests is high (~$750/site). A database of available information has been compiled and is supplied with the latest version of GrassGro. GrassGro users are also finding innovative ways to gather local soil information. Continuing advances in technology, such as the development of mid-infrared soil analyses (Merry and Janik 2001), also promise to reduce these costs and will inevitably improve access to quantitative soil information.

(4) The initial design for GrassGro envisaged advisors using it to tailor information for specific clients and sort through farm-specific management issues. The advisor would need to spend some time establishing a GrassGro simulation for each client's enterprise, but subsequent uses of the tool for the client would be very rapid. In practice, advisors have preferred to use GrassGro to analyse district-related questions that can benefit client groups because of the time (a few days) they need to establish and "reality check" each client's GrassGro profile. Feedback on these issues from GrassGro users is presently being used to guide development of production system "templates" which will greatly reduce the time needed for advisors to establish new GrassGro simulations and should ultimately encourage a move toward more farm-specific simulations. The challenge is the make the tool simpler, to broaden its appeal, without compromising its flexibility and capacity for analysis of complex production questions.

(5) There are large gaps in knowledge of pastures and soils. There is a pressing need to describe more "desirable" and "weedy" pasture species for inclusion in the library of plants that GrassGro can simulate. GrassGro is based on our current understanding of the biology of grazing systems. As science generates new knowledge the models underlying GrassGro will be improved and graziers who use the tool will benefit from the new information.

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THE POTENTIAL GAINS ACHIEVABLE THROUGH ACCESS TO MORE ADVANCED/MECHANISTIC MODELS OF RUMINANTS.

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The main objectives of more advanced/mechanistic animal models are (1) to broaden the application of the models to a wider range of management questions and decisions, (2) to improve the accuracy of the predictions and (3) to reduce the cost of the input information required. Accounts of the development of the decision support tools AUSPIG, GrazFeed, based on the Feeding Standards for Australian Livestock (SCA 1990), and GrassGro, based on the animal model in GrazFeed, all discussed above, provide examples of these objectives. There is an ongoing demand for further improvements in the animal models on which these and other Decision Support Tools are based. Taking the management of cattle feedlots as a particular example, the National Research Council (NRC) in the USA supported the further development of the cattle growth model to include a more detailed representation of the rumen microbial population and of the degradation of feed components. The modified cattle growth model is called the "level 2" feeding system for cattle (NRC 1996). A significant improvement in accuracy was achieved through the use of the level 2 feeding system (reviewed by Buchanan-Smith and Fox (2000)).

Despite these changes, the level 2 NRC Beef model still does not address tactical management questions which are important for (Australian) cattle feedlots, such as, "Can a change in the daily feeding pattern reduce the risk of severe heat or cold stress given an expected pattern of hourly temperatures?" Nor have other long-standing questions been adequately addressed by the current feeding systems, questions important to both the cattle and dairy industry, such as, "What is the risk of rumen acidosis given a particular change in diet involving a change from forage to concentrate?" To provide information and advice relevant to these questions requires the modelling of physiological changes; quantities such as body heat production, body temperature and rumen pH must be calculated on an hourly or shorter time step. At the moment all ruminant feeding systems, including GrazFeed, make predictions of the average daily animal performance. To predict hourly performance requires a quantum jump in the complexity of animal models. It requires, for example, more mechanistic model of the rumen microbial population and of feed particle dynamics in the rumen. Predictions of hourly body temperature and rumen pH also mean that voluntary feed intake must be modelled using a small time step.

Models incorporating a more mechanistic representation of the rumen have been attempted by several research groups. These are considered to be research models and examples include the Wageningen rumen model (Dijkstra, 1993) and the rumen sub-model in "MOLLY", a model of a lactating cow (Baldwin, 1995). The Wageningen rumen model represents the microbial population as two groups, a fibrolytic group and the remaining microbes in a second group (Dijkstra 1993; Dijkstra, 1994). The second group was subsequently split into an amylolytic group and a protozoal group. The Wageningen rumen model does not represent (voluntary) dynamic feed intake nor does it adequately account for feed particle dynamics. MOLLY on the other hand represents the entire microbial population as a single pool, but distinguishes between those microbes attached to feed particles and those unattached.

Drawing on the experience of other research groups as much as possible, we have now constructed a (CSIRO) ruminant model consisting of a rumen sub-model, which includes representation of feed particle dynamics and a multi-group representation of the microbes, a lower-gut sub-model and a body growth sub-model. Since we wish to consider hourly variations in rumen pH and whole-body heat production, we have also included a voluntary feed intake sub-model that attempts to capture some of the variation in feeding observed in feedlot feeding trials. Some predictions of the (CSIRO) ruminant model showing the performance of both the rumen function and voluntary intake (in a feedlot) sub-models and using a time step of the order of a minute are presented below.

RUMEN SUB-MODEL

Feed particle dynamics

The dynamics of feed particles is modeled within the rumen sub-model by classifying each feed ingredient into one of three feed types, namely, forage-stem, forage-leaf and grain. Each of the feed types in the rumen is divided into four particle sizes, namely, large (L), medium (M), small (S) and fine (F). The nutrients in the feed are regarded as being locked together in the L, M and S particles, while the nutrients in the F particles are considered to be in solution. Consequently only the nutrients in F particles are available for fermentation. L, M and S particles are, however, available for engulfment by the protozoa. The different processes acting on feed particles and represented in the rumen sub-model are shown in Figure 1. L, M and S particles are broken down by "fragmentation", a physical process caused by chewing and rumination, and also by "microbial degradation" achieved by microbial attachment and the enzymatic breakdown of feed particles.

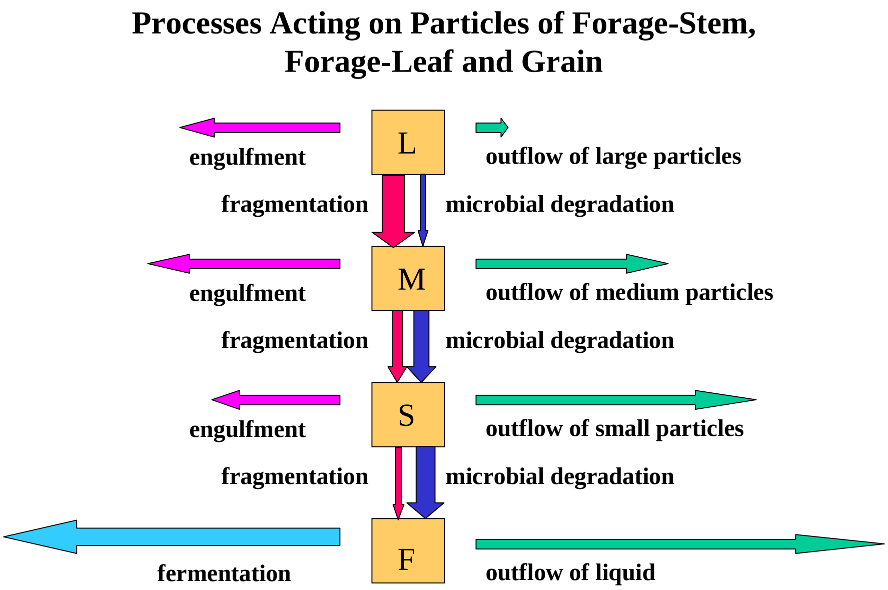

Figure 1.

Although it is not shown in Figure 1, fragmentation and microbial degradation also cause direct breakdown of L and M particles into F particles. The size ranges of the particles are chosen so that the fractional outflow rate of large particles is approximately zero and the fractional outflow rate of F particles is the same as the fractional outflow rate of liquid.

Representation of microbial population

Published information describing observations of rumen microbial function was collected for sixteen microbial genera, which were then grouped and modelled as four microbial groups (Nagorcka *et al.*, 2000). The four microbial groups were constructed on the basis of:

- Substrate preferences and fermentation stoichiometries, and
- Preferences for attachment to a particle size class leading to intrinsic differences in fractional outflow rates of the microbial groups from the rumen relative to the liquid fractional outflow rate.

The four microbial groups chosen to represent the total microbial population were:

1. Fibrolytics --- exhibiting a preference for cellulose and hemi-cellulose, and a capacity to attach to M and S fibrous particles.
2. Amylolytics --- exhibiting a preference for soluble carbohydrates and starch, and a capacity to attach to M and S high starch particles.
3. Lactolytics --- exhibiting a preference to ferment lactate.
4. Protozoa --- exhibiting differences in fermentation stoichiometry and a capacity to attach to L, M and S particles and to engulf both particles and rumen bacteria.

Microbial fermentation

Previous rumen models such as the Wageningen model and that used in MOLLY were found to have difficulties in predicting molar proportions of volatile fatty acids (VFA's). Nagorcka *et al*. (2000) suggest that this is due to the fact that the fermentation stoichiometries used in these models, i.e., those proposed by Murphy *et al*. (1982) and Murphy (1984), are associated with dietary components only and do not depend on the microbial group utilizing the dietary component. In the rumen sub-model used here, new stoichiometries have been derived for each of the microbial groups and for each dietary component utilized by that group. Consensus stoichiometries were derived by combining the stoichiometries for individual bacterial genera or protozoal types in proportion with the contribution of the individuals to the functional group. Further details are given by Nagorcka *et al*. (2000) who consider the total microbial population to be divided into three groups. In this paper the total microbial population is classed into four microbial groups. The same improvement in predicting VFA molar proportions in the rumen noted by Nagorcka *et al*. (2000) has also been achieved here, where a lactolytic group is now considered as a separate group. The improvement in predicting VFA proportions is due to the fact that VFA proportions are dependent on microbial composition as well as on the composition of the dietary components in the rumen.

FEED INTAKE SUB-MODEL

The data collected in feeding trials in research feedlots includes information about each feeding event for each animal in a pen and this can be used to characterize the feeding behaviour of cattle in feedlots. Different breeds have different feeding characteristics (Robinson *et al*. 1996). The *ad libitum* feeding of *Bos taurus* in feedlots normally consists of an average four to seven feeding periods separated by periods of zero intake during each day. However, there is considerable variation in the actual number of feeding events each day as well as in other characteristics of a feeding event, such as the amount eaten and the duration of the event. The discontinuous feeding behaviour in feedlots is expected to have a significant effect on the hourly variation in quantities such as rumen pH and body heat production.

To model *ad libitum* feeding a metabolic mechanism that drives the desire to feed has been included in the CSIRO ruminant model. While many factors influence feeding behaviour it is assumed that the main driving mechanism is the need to maintain the total energy of metabolites in the blood within specified thresholds. Other factors controlling the desire to eat, such as the discomfort level of the dry matter or volume in the rumen, and the requirement for a particular balance of different nutrients in the pool of available metabolites, are also included in the CSIRO ruminant model as limiting factors.

LOWER-GUT SUB-MODEL

There are many chemical/nutritional components of the feed consumed and the undegraded fractions of these components flowing out from the rumen into the lower-gut are calculated in the rumen sub-model. In addition, the different fractions of the fermentation products and of the four microbial groups flowing out of the rumen into the lower-gut are also calculated. The lower-gut sub-model describing the digestion and absorption of these nutrients flowing out from the rumen into the post-ruminal gut is the simplest of the sub-models forming the CSIRO ruminant model. At the moment, for the sake of simplicity, fixed values are used to calculate the fraction of each nutrient component digested, except for starch, as it flows through the lower-gut. The digestibility of the undigested starch is calculated as a function of the rumen digestibility of starch for different starch components. Fixed values are also used to calculate the fraction of the microbial cell wall, protein, non-protein-nitrogen and fats digested and absorbed in the lower-gut.

BODY GROWTH SUB-MODEL

The sub-model calculating body growth currently being used is a modified form of the body growth sub-model used in MOLLY (Baldwin 1995). A description of the modifications will not be given here. As described by Baldwin (1995) this sub-model is based on a mechanistic view of the growth of three body components, namely, “lean body mass”, “viscera” and “fat”, and makes use of a biochemical understanding of the processes involved. The intermediate metabolites, propionic acid, lactate, triose phosphate and glycerol are included in the calculations although they do not exist as pools within the sub-model. Other metabolites, such as amino-acids, glucose, acetic acid and fatty acids, do exist as pools and control the rates of synthesis and degradation of the three body components depending on their concentration in the blood. Absorbed nutrients from the lower gut and the rumen flow directly into pools of these metabolites.

SHORT TERM DYNAMICS OF THE CSIRO RUMINANT MODEL

Simulation

The CSIRO ruminant model has been executed using a ration containing 50:50 forage:grain, where the forage and grain have the chemical components shown in table 1. The forage is regarded as being made up entirely of “stem” with no “leaf” component. In a simulation this ration is fed to a young steer (200 kg empty body weight) for a period of 100 days.

Table 1. Chemical composition of forage and grain components (g/kg).

Ingredient	Protein			Fibre		Starch	CHO	Lipid
	Undeg.	Deg.	Sol.	Undeg.	Deg.		Sol.	
Forage	30	40	60	120	500	15	115	30
Grain	25	75	30	20	200	440	100	50

In the simulation the amount of feed offered was initially restricted, but after several weeks 8 kg of the concentrate was added to a trough once a day. At first the 8 kg was more than sufficient to meet *the ad libitum* requirement calculated by the model. The excess accumulated in the trough. As the animal grows the 8 kg becomes less than the *ad libitum* requirement, but the animal was able to eat a little in excess of this amount because some feed had accumulated in the trough from previous days. Eventually, however, the appetite of the animal increased, the accumulated feed in the trough was used up and the trough was emptied each day. Since we wish to examine only the short-term dynamic behaviour of the CSIRO ruminant model, the model predictions during a 15-day period, chosen towards the end of the simulation period, are presented below. The 15-day period was chosen at a time when the trough was eventually emptied by the animal during the course of the day, which triggered a change in feeding behaviour.

Results

The effect of the metabolic control on eating, a major mechanism in the voluntary intake sub-model, can be seen in Figure 2a where the calculated rate of eating is plotted during the chosen 15-day period. The parameters defining the metabolic control in the intake sub-model are set so that there are two feeds per day for much of the simulation. The number of feeds per day would normally be closer to 4 or 5, but this would make it considerably more difficult to graphically illustrate some of the model predictions. During the chosen 15-day period the trough begins to run dry in the course of the day (Figure 2b) and this causes a change in feeding behaviour according to the model; the number of feeds per day changes from two feeds to one feed per day (Figure 2a). It can be seen in Figure 2c that during the 15-day period the average 24-hour intake (calculated continuously) changes from a little above 8Kg per day to be exactly 8Kg per day.

The effect of the variation in the intake on the calculated continuous outflows of undigested fibre and starch from the rumen is shown in Figure 3a. There are large variations in these rumen outflows in response to the variations in intake. The 24-hour average (calculated continuously) of these outflows, on the other hand, remain relatively steady, although the averages do change in response to a change in feeding behaviour. The rumen digestibilities of both fibre and starch (Figure 3b) have been calculated using the 24-hour average intakes of fibre and starch. There are large variations in the digestibilities reflecting the variation in continuous rumen outflows of fibre and starch. Once again much of this variation is removed when a 24-hour average of the digestibilities is calculated. The model predictions suggest that the change in feeding behaviour has a small but significant effect on the digestibility of both fibre and starch.

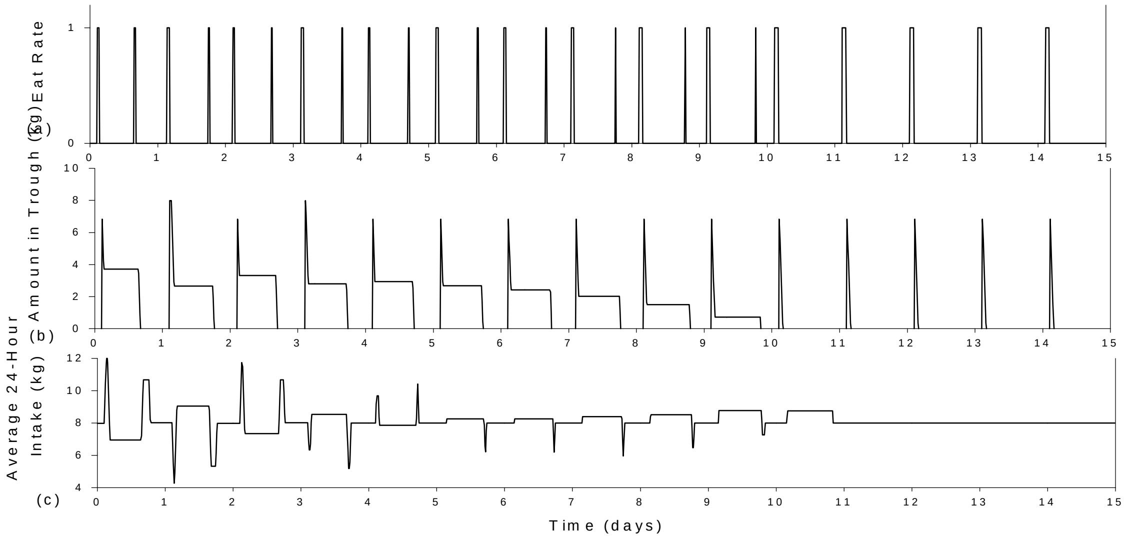

Figure 2. Voluntary intake from trough; (a) times and rate of eating, (b) amount left in the trough and (c) the average intake calculated over the previous 24 hours.

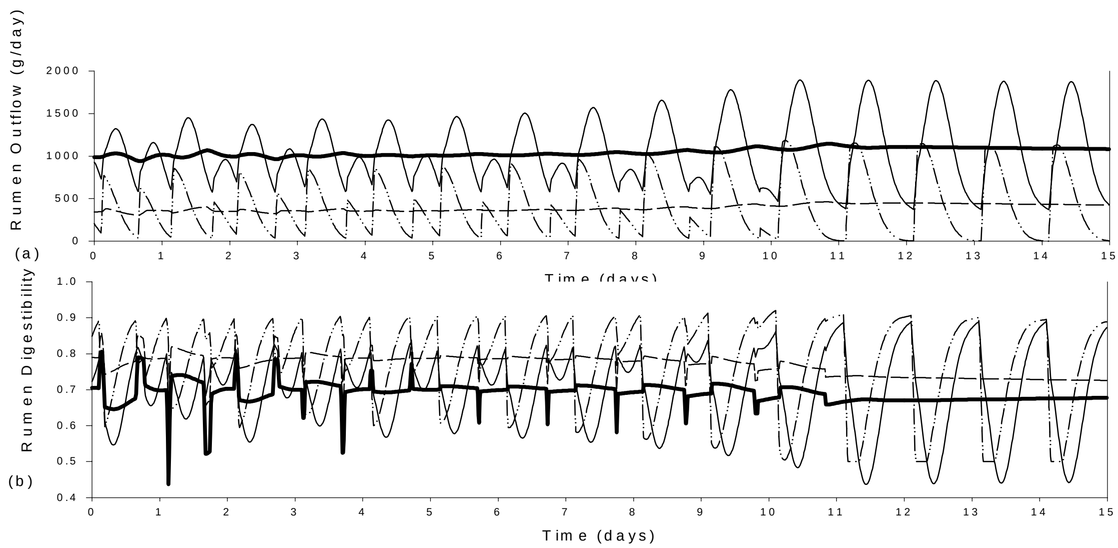

Figure 3. (a) Rumen outflows and (b) rumen digestibilities of fibre (dynamic – thin solid line, 24-hour average – thick solid line) and starch (dynamic – dash-dot-dot line, 24-hour average – dashed line).

The total heat production is also calculated continuously and the predicted daily pattern of heat production is plotted in Figure 4a. Although much of the heat produced is the result of metabolism in the body tissues, once again substantial variation (~20%) is predicted to occur during the course of the day on concentrate diets. The variation increases if feeding behaviour is changed, leading to a reduction in the number of feeds per day. There is significant delay between the time of intake and maximum heat production. The size of the variation and the shape of the heat production curve, i.e., the delay between eating and maximum heat production, and the duration of maximum heat production, are important in devising strategies for minimizing the risk of heat stress.

The predicted rumen pH is plotted in Figure 4b. The effect of the size and number of feeds per day clearly has a significant effect on the variation of rumen pH. In this case too the size of the variation and the shape of the variation in pH are important in calculating the risk of rumen acidosis in response to diet changes and factors affecting feeding behaviour.

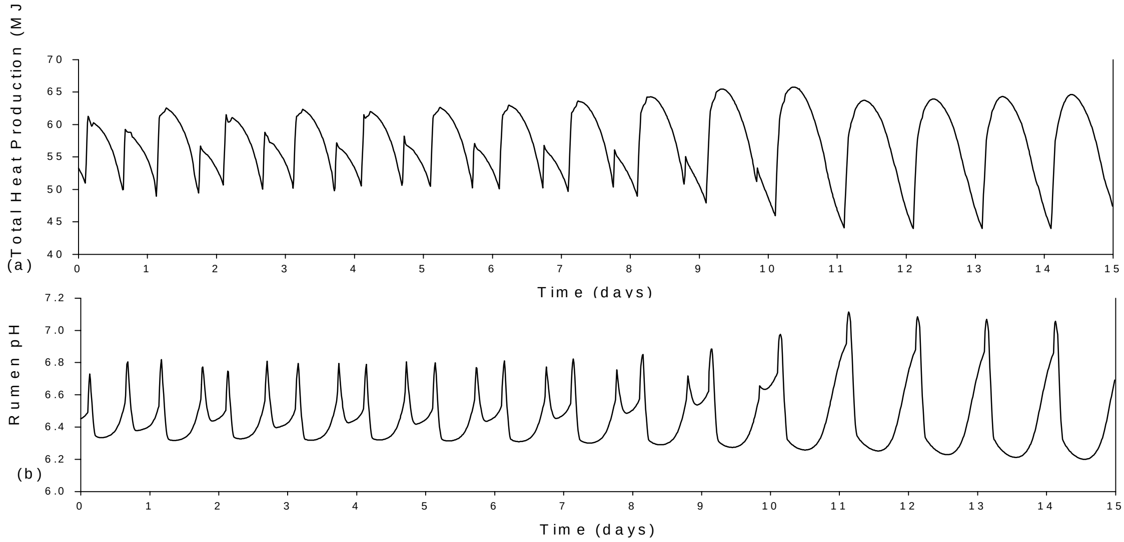

Figure 4. (a) The rate of total heat production, and (b) rumen pH.

FUTURE ANIMAL FEED ADVISORY SYSTEMS

Current animal feed advisory systems predict average daily values and rely heavily on stochastic empirical relationships to achieve this. The results shown above demonstrate that even where daily averages may be steady, there are still large variations occurring in most quantities during the course of the day. Predicting these large daily variations is essential to offer management advice about such things as controlling heat stress and minimizing the risk of rumen acidosis and hence to maximizing productivity of the system.

The capacity to predict variations in animal function and performance occurring through the day requires a much more detailed and mechanistic animal model than those currently used in animal feeding systems. In particular, the dynamics of feed particles in the rumen, variations in microbial composition and the short-term dynamics of feed intake must all be represented. The chemical and physical characteristics of feed ingredients that determine their rate of breakdown in the rumen in response to physical and microbial processes must also be supplied. Although it is an ambitious goal, attempts are being made to construct and validate animal models at this level of detail. The more detailed models now being constructed will not only allow questions concerning heat stress and acidosis to be considered, but also many other important questions, such as, the interactions between dietary components, level of intake, feeding behaviour, and the effect of these on digestibility and the site of digestion.

The arguments against using more complex animal models are 1/ that they are too difficult to use, 2/ that they require much more detailed inputs, and 3/ that they require much more detailed experimental information to validate. In fact, by using computer based decision support tools the more complex animal models can now be offered as an alternative model in the form of an icon which is no more difficult to use that existing feeding systems. It is true that they require more detailed feed information, but, at least in the case of decision support tools for enterprises based on intensive feeding, this is becoming available as a computer database that can be readily accessed by the decision support tools themselves with no additional demands on users. In principle decision support tools for grazing enterprises would require the use of a pasture model, as is the aim in GrassGro, to minimize the need for detailed feed information. The more complex models actually assist in identifying those chemical and physical characteristics of feeds that determine their performance as animal feeds and this has several advantages, one being that it reduces the need for expensive *in vivo* animal experiments. More detailed experimental information is required to validate the more complex models, but such experiments are required anyway where it is necessary to provide answers to serious management questions. Finally, as each more detailed animal model is developed it becomes possible to address a wider range of both tactical and strategic management questions.

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SYMPOSIUM CONCLUSION

A range a examples have been presented that clearly demonstrate how each of the Decision Support Tools discussed here are able to provide advice to consultants and managers of livestock enterprises with the potential to improve their profitability, while still adhering to the environmental and health standards set by the community. In fact, each of the Tools tries to provide advice on how to maximize profits given the correct description/representation of the particular enterprise. As a consequence AUSPIG has become a standard tool for the Australian pig industry, and GrazFeed has become a standard for the grazing industry in NSW. GrassGro has only recently been released, but given its adoption in tertiary educational courses it's use is also expected to grow towards an industry standard. The rapid spread of personal computers, not only into tertiary educational institutions, but also into high schools (and primary schools, means that the adoption and use of Decision Support Tools in the agricultural industries will continue to grow rapidly.

Improvements and upgrades of the mathematical models on which these Decision Support Tools are based are continuing. This is being achieved while maintaining the essential nature of the existing user interface so that even major improvements will not introduce barriers to the ease of use of the Decision Support Tools. However, as the management questions considered increase in complexity, the challenge to maintain and improve the ease of use of these tools is also increasing. Nevertheless, it is concluded that the adoption of Decision Support Tools will continue to grow in the future, allowing consultants and managers to readily explore a wide range of options with the potential of achieving significant financial gains for the livestock industries.

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