DECISION SUPPORT: DELIVERING THE BENEFITS OF GRAZING SYSTEMS RESEARCH

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ABSTRACT
Decision support tools (DS tools) are now adding value to the way research can be implemented for greater efficiency in the management of grasslands. Once a DS tool is released, the development team must deal with issues such as maintaining the user interface; the provision and updating of suitable input data; and evaluating both the underlying science and the software. Some successful uses of simulation models to add value to physiological and agronomic research are presented. The GRAZPLAN family of Australian DS tools is used as an example to show how production issues can be resolved and also how public policies relating to grassland use can be influenced. Some future opportunities arising from recent advances in information technology are discussed.

KEYWORDS
Decision support, grazing systems, computers, modelling.

INTRODUCTION
At the last International Grasslands Congress, Seligman (1993) was somewhat pessimistic about the level of progress achieved over the past 20 years in using models to manage grasslands. Computer models had been advocated for many years as a better way to judge the impact of management decisions (e.g. Morley, 1972). In practice the use of models has proved difficult and has mostly been limited to research groups. Four years later, we believe there are more grounds for optimism. Decision support tools (DS tools) derived from research models of grazing systems are being used by groups other than those that originally developed them and at least some are having an impact on the way grasslands are managed (see e.g. Cohen et al., 1996; McCall et al., 1993).

The increasing value of DS tools as management aids has been made possible by grazing systems research that has led to a better understanding of main biological processes underlying the production of milk, meat and fibre, and by significant new developments in informatics[1]. Prior to the advent of computer models, the impact of even single processes on the productivity of a whole grassland system was difficult to judge. While early models of grazing systems provided clear messages of how some of the biological processes worked (e.g. Morley, 1968; Noy-Meir, 1975), 25 years later they have had little impact on how graziers (ranchers) manage their pastures. Difficulties in relating a theoretical analysis to practical on-farm applications, where interaction with other processes will occur, has been the major obstacle. Recently, advances in computer hardware and radically new software developments have made possible the construction of DS tools which are based on more comprehensive models and which are much easier to use than the research models. The tools allow interaction with local environmental, managerial and economic inputs. Graziers or their advisors using DS tools can use them to apply knowledge in relation to their own experience and practice.

An additional impetus that is increasing the demand for DS tools is a much greater emphasis on sustainability of grazing systems. Changing community values are resulting in greater use of grasslands for water catchment and recreation. The need for new DS tools, with a dual role in the improvement of management, for both the traditional uses of grassland for grazing and for the formulation of community policy on alternative uses (Bosch et al., 1996), is now critical. Unless the profitability and sustainability of grazing systems can be assured, alternative land uses seem likely to displace grazing in many situations. Moreover, serious conflict between community groups and traditional land owners may occur unless graziers address land degradation caused by increasing salinity, acidification and erosion. Well designed DS tools provide the opportunity to do this systematically.

In this review we outline some industry applications which support our optimism about the value of DS tools. It is based largely on our own experience with the GRAZPLAN family of DS tools for managing grazing enterprises in temperate Australia. We discuss the new issues of model maintenance, interaction with users, and provision of necessary input information which come to the fore as DS tools become established as an efficient way of transferring technology. While DS tools that are suitable for developing broad community policy for the management of grasslands and those designed for guiding on-farm decisions may share the same process models and data, the approach to design and implementation will differ in line with the needs and expertise of these two groups of users. Therefore, we outline an alternative approach for development to that described by Stuth et al. (1993) which we have found to be very effective in the grazing industry in southern Australia. We raise several limitations in knowledge of the biology of processes in grazing systems that in our opinion are limiting wider use of DS tools. Finally, we give a brief preview of some of the opportunities that new decision support technology will provide to grassland managers in the future.

DECISION SUPPORT TOOLS IN ACTION
DS software can succeed in the management of grazing lands. The proof of this assertion lies in the DS tools which are in use, are receiving ongoing support or development, and are delivering benefits to managers of grazing lands. As examples, we have selected four tools which meet all three of these criteria. Two of them are aimed at strategic planning of grazing enterprises, and two focus on nutritional management of grazing animals.

GLA. The Grazing Lands Application package (Stuth et al., 1993) was developed under contract for the U.S. Natural Resources Conservation Service (NRCS) to assist technical advisors in conservation planning. Areas covered by the package include a stocking rate calculator, nutritional advice, forage inventory and balances, and various economic analyses. The system was designed to reflect and expand on NRCS' existing planning processes. Since its release in 1991, the NRCS has distributed GLA to over 35 states, a process which has involved a major effort to train users and provide them with pre-packaged soil, plant and site information. The total cost of this effort has been roughly 75% of the cost of writing the software (J.W. Stuth, pers. comm.). NRCS now maintains the software, releasing the developers for other activities.

Stockpol. The Stockpol tool (Marshall et al., 1991) was developed

[1] Informatics is the use of mathematics, statistics, and computer science in research and development and in the communication of research results.

specifically as a productivity tool for advisors with Agriculture New Zealand, who use it in one-to-one consultations with graziers about property planning issues, especially relating to flock structure and feed-year planning (McCall and Tither, 1993). The tool has now been in regular use since 1991. Webby et al. (1995) conducted a thorough evaluation of the pasture production model underlying Stockpol.

GrazFeed. This DS tool (Freer et al., 1997) predicts production by grazing animals using a model based on SCA (1990), and has been used mainly by extension personnel to provide tactical advice on supplementary feeding of livestock. The software has been in use since 1989 and has undergone about 15 upgrades since its release, largely in response to feedback from its user community. The benefit to graziers from investment in GrazFeed by CSIRO (the Australian national research organisation) in one drought year in southern New South Wales alone was at least 15 times the cost of the software development; nationally it is certainly much higher. Recently the software has been in demand from producers as well as advisors; there are now over 850 licensed users.

NUTBAL/NIRS. The NUTBAL software package (Stuth and Lyons, 1995) performs a similar task to GrazFeed, but is based on the NRC (1996) feeding standards; it was originally developed as a module of GLA. Since 1994, the Ranching Systems Group at Texas A&M University has been operating a unique advisory service which couples the NUTBAL software with measurement of feed quality characteristics through near-infrared spectroscopy of faeces (Stuth et al., 1989). Users of the system provide faeces from the livestock of interest to a laboratory, together with a form describing the circumstances under which they were collected. They then receive a report containing the results of the NIRS analysis and interpretation through the NUTBAL program. In 1995 more than 350 ranches were using the system.

The mode of delivery and the success of a DS tool do not seem to be connected. GLA and GrazFeed are largely used by public-sector advisors, while Stockpol and the NUTBAL/NIRS service are delivered on a strictly commercial basis. These programs do, however, have a key element in common: they are designed to be generic in their operation, while still allowing specific circumstances to be evaluated.

WHAT ARE THE ISSUES FOR DS TOOLS ONCE THEY ARE OPERATING?

The place of the DS tool in the operations of the client. Learning to use a DS tool entails an expenditure of effort. While this effort can be minimised by careful attention to the software's interface, any useful DS tool will contain conceptual content which must also be understood if the tool is to be used effectively. For example, GrazFeed can be run with half-a-dozen inputs; but to make good use of it, a user must also possess a reasonable quantitative understanding of ruminant nutrition and the practical skills to assess the quantity and quality of forage. To be accepted, the benefits of a DS tool must outweigh the cost of learning it. This is why successful DS tools tend to be generic: they can be applied more often. The likelihood of successful adoption will be enhanced if a DS tool analyses a complex situation with relatively simple inputs (e.g. GrazFeed), or if it combines numerous data inputs using relatively simple operations, e.g. HerdEcon (Stafford Smith and Foran, 1988).

User interfaces. A well designed user interface is an essential feature of a DS tool. Simplicity is crucial to minimise the effort required to obtain a benefit. The interface has to suit the culture of the users and, except in the simplest cases, this must be done through the iterative process of consultation and re-design described so well by Stuth et al. (1993). Iterative prototyping does not end when the DS tool is finally released. Indeed, one sign that a DS tool is succeeding is requests by users for more functions or different ways of viewing results. This, and the need to keep technical content up to date, can result in a steady flow of software upgrades (2-3 per year for both the GrazFeed and NUTBAL programs). However, if a DS tool is designed to have an extended life, the costs of maintaining the technical content must be allowed for.

From the moment of release, the interface of a computer-based DS tool starts to become outdated. In particular, applications which were developed for the MS-DOS operating system risk being disregarded by users who are familiar with Microsoft Windows™. Experience at CSIRO suggests interfaces will have to be re-built every 5-10 years to remain commercially acceptable. We estimate that converting the MetAccess (Donnelly et al., 1997, Figure 3) and GrazFeed software from MS-DOS to Windows required 50% and 20%, respectively, of the cost of the original software development; re-coding GrazFeed was much faster because the design processes and coding conventions developed in porting MetAccess could be re-used.

There are strategies which can be adopted to contain the cost of keeping a DS tool up to date. Where a team develops a suite of DS tools, as in the GRAZPLAN family (Figure 3), following a consistent design across the component tools reduces the overall development time. Alternatively, where the computer element of a decision support system can be centralised, the cost of developing user interfaces can be sharply reduced. The faecal NIRS/NUTBAL system described above is a good example; because communication with the user is primarily via the printed page, the need to develop and maintain the computer interface is not great. The resulting savings make this "service" method of delivery commercially attractive.

Provision of inputs. The input information required by DS tools will vary with their purpose and scope. Wight and Hanson (1993) have suggested that an expert system would be a useful tool to provide parameters for complex models. In our opinion, the provision of parameters for the underlying models of a DS tool is not a user responsibility. Indeed, we believe that the bulk of these parameters should be hidden from all except the most experienced of users.

Where a DS tool relies on an underlying biophysical model, the requirement for location-specific soils or weather information can become a major constraint to adoption. For example, the NRCS has invested in pre-packaged information to gain acceptance of the GLA tool by its staff (J.W. Stuth, pers. comm.). When users cannot readily measure data inputs, there are really only two alternatives: databases from which suitable information can be extracted, and schemes for computing default values. It is important, though, to keep these imperfections in available information in perspective; after all, farm managers are used to dealing with imprecise information.

Weather data provide a good example of the issues surrounding information provision. Most analyses of pasture production will require at least rainfall and temperature data, but access to the very large data bases maintained by national meteorological organisations is usually difficult, slow and expensive. For example, the Australian Bureau of Meteorology has rainfall records for more than 16,000 stations, but until recently fast access to these data was not feasible. The advent of cheap technology for producing compact disks, coupled with efficient software for personal computers, has greatly increased access to weather data (Donnelly et al., 1997). Even so, there is no consistency in the formats used for providing the data to models and

DS tools even within a single country (Clewett et al., 1994; McCown et al., 1996; Donnelly et al., 1997), despite efforts to define a standard (IBSNAT 1990). The U.K. Meteorological Office now regards weather data as a commercial commodity, not a public resource. This short-sighted policy has already caused problems for at least one publicly-funded DS development (J.A. Milne, K.D. Farnsworth and A.R. Sibbald, pers. comm.).

Weather data are almost always incomplete and some sort of scheme must be applied to fill the gaps. Again, there is a plethora of methods for this task (e.g Wight & Hanson, 1991; Meinke et al., 1995) and considerable duplication of effort. Also, the provision of default inputs can lead to prediction errors: for example, Wight and Hanson (1991) found that rainfall data from stochastic weather generation models failed to predict extreme rainfall events which have a large effect on outputs from grassland models. Nonetheless, it is possible to develop weather data-handling and filling procedures to the point where they are transparent to program users, e.g. in GrassGro (Moore et al., 1997a).

There is an analogous situation with soils information, where with the exception of the United States, extensive soil data bases are generally not readily accessible. Thus defaulting schemes for soils information must play an important role in DS tools. A simple but effective example from the GrassGro DS tool is the use of soil texture classes to describe soil water holding characteristics. The defaults can be easily modified for any soil if more specific information is available.

Organisational commitment. The maintenance of a fully functional DS tool with well-tested underlying models is a major undertaking in both science and software engineering. The time lags in adoption are likely to be significant, although comparable to other innovations for grazing enterprises. The developing organisation must therefore be prepared to make a long-term commitment to a DS effort. We suspect that relatively little attention has been given to the very substantial commitment of resources required to ensure that a DS tool continues to reflect scientific advances. Unless this issue is taken seriously, the DS tool will rapidly become obsolete and the confidence of its users will decline. In Australia, for example, the team that developed the SHEEPO DS tool (McPhee, 1993) for sheep flock management has been disbanded and the software is now being maintained by another organisation. Further development, however, seems unlikely. Where a DS tool is developed under contract to a specific client, it is possible to transfer responsibility for maintenance to the client organisation, as has happened with GLA.

The users and developers of grazinglands DS tools often belong to different organisations. An official agreement between CSIRO and New South Wales Agriculture for the support of GrazFeed has been the keystone of its successful and widespread use throughout that State. Adoption has been much slower in other States where CSIRO did not seek this commitment. Staff training is a key area where a long-term commitment from a user organisation is required. The developers will often need to play an initial role in this training, especially where the technical content of the DS tool is large. In CSIRO we have contributed to training users in two main ways: firstly through regional workshops for advisory staff, and secondly through arranging for officers of user organisations to be placed with the development team; here they can build expertise in using the DS tools.

Evaluating the science and the tools. The higher the technical content in a DS tool, the more important model evaluation is for user confidence. Authoritative backing for a model, such as the ruminant feeding standards discussed elsewhere in this paper, will be the exception rather than the rule. Even so, extensive evaluation is essential, especially at the margins of a DS tool's range of uses. Evaluation is time consuming, potentially frustrating, and tends to lack in rewards through research funding or publication. A possible solution lies in the development with universities of courses where DS tool evaluations, together with practical application in case studies, can form part of post-graduate degree work.

Evaluation needs to extend beyond models to the DS tools which are based on them. Different levels of evaluation are required at different stages in the life of a DS tool. We advocate the use of the following staged scheme, which is largely based on work of R. Clark and D.M. Stafford Smith (see Stafford Smith et al., 1997), for planning the evaluation process:

Verification. At this stage, the question is whether a DS tool addresses the intended problem area, and represents the problem in a reasonable way. This level of evaluation will typically be carried out within the developing group during the design process.

Confirmation. A tool may be considered "confirmed" when tests with an initial user group (which has had prior involvement in the development process) show that the tool is useable and meets the users' needs. Scientific evaluation of any underlying models falls within this stage of the evaluation process.

Change in reaction. The next stage of evaluation is to present it to previously uninvolved members of the ultimate client group, to see whether they spontaneously find the tool valuable.

Change in knowledge, attitudes, skills and aspirations. The aim at this level is to seek evidence that the ultimate client group have understood the basis of the tool, have gained the skill to use it in their decisions; and have adjusted their expectations relating to the decisions it supports.

Change in practice. The last and most important level of evaluation is to measure whether management has actually changed as a result of the tool's deployment. Criteria at this stage will include:

- the tool is in regular use as a part of decision-making;
- improvements in targeted management practices are measured;
- benchmarks for client-defined "local best practices" in an area improve.

The evaluation of DS tools will most likely proceed in an iterative fashion, but at least the first three stages need to be addressed before the first software release. Evaluation does not come free: the last two stages both require baseline and follow-up measures of the client group's knowledge, attitudes and practices, and changes in practice will often take time to become measurable. The discipline of being open to evaluation will, however, increase the quality of DS developments. Evaluation processes will be of most value when developers can treat them as an opportunity for learning about their craft.

RESEARCH MODELS IN ACTION

Apart from a role in delivering technology to industry, DS tools can also provide scientists with powerful ways to undertake independent research. For example, it is possible to extend the range of pasture species that can be simulated by GrassGro through re-defining parameters for the plant model without the need for re-coding. This has enabled J.M. Scott and colleagues from the University of New England in northern NSW to develop additional parameter sets to describe pasture species of which we have no experimental knowledge. The advantage for the UNE researchers is access to an existing, well-tested grazing systems model with a simple user interface to drive it. Likewise, R.D.H. Cohen and colleagues at the University of Saskatchewan in Canada have developed parameter sets for pasture species such as *Agropyron cristatum* which grow under environmental extremes which are not experienced in Australia. In each situation, the work undertaken by these independent groups has proved fruitful in guiding CSIRO to make improvements in the generic nature of the pasture model. Similarly, the SPUR model, which was originally developed by the USDA-ARS in Colorado (Wight and Skiles, 1987), is also used at Texas A&M University, which has developed a user-oriented version (Carlson & Thurow, 1991).

DS tools can be of great value in drawing inferences about processes in experiments where it is not feasible to make direct observations, but it is essential that the scientists have confidence in the models incorporated in the DS tool. A research team attempting to quantify fluxes in the nitrogen cycle of grazed pasture in southern New South Wales have used the GrazFeed DS tool to estimate nitrogen excretion in urine by sheep without having to collect the urine and so disrupt the nitrogen cycle. Intakes and faecal outputs of nitrogen were measured using plant alkanes as feed markers (Dove and Mayes, 1991). Since GrazFeed's predictions were in agreement with these measurements, its estimates of urinary nitrogen excretion were taken to be reliable.

Hypothesis generation using models has long been proposed as one of the major contributions that grazing systems modelling offers for increasing efficiency when planning research . A classic example of hypothesis generation was achieved using the GRAZPLAN DS tools (Figure 3) to identify a new sale system for large lean lambs (see below) that was feasible, more profitable and entailing only slightly greater risk than the conventional system based on smaller prime lambs. Experimentalists in the region are now seeking resources to test this prediction.

Bridging the gap between plant physiology and farming. Well designed process-oriented models can be used to explore the likely impact of new selection programs that aim to improve yield or other forage characteristics of pasture species. Donnelly et al. (1994) used the GRAZPLAN pasture and animal simulation models (Freer et al., 1997; Moore et al., 1997b) to estimate the impact on sheep production of an increase in winter pasture growth at Canberra, in south-eastern Australia. The main purpose was to investigate physiological mechanisms that might provide a worthwhile response in winter growth of pastures, if this was under selection in a breeding program. Our simulations explored the impacts of two different mechanisms on winter growth of *Phalaris aquatica* L. First, a shift in distribution of assimilate between underground storage and top growth was examined by setting parameters to switch from vegetative to reproductive growth earlier in the season. Simulations showed that the timing of the switch, autumn or mid-winter, had only a small effect on daily top growth. Low winter temperatures over-rode any potential advantage at the site where the simulations were made. Second, the benefits of increasing cold tolerance were examined. A downward shift of 1°C in the low temperature growth response increased daily growth rate by 25% between mid-autumn and mid-spring in 50% of years. In other years, lack of rain in autumn limited growth. The financial benefit was substantial as long as stocking rates were increased to use the additional feed.

Hanson et al. (1993) and Eckert et al. (1995) used models to examine a question even less amenable to analysis other than by modelling: changes in livestock production and consequent economic outcomes expected under a number of climate change scenarios across the rangelands of the United States. They found that production was likely to increase in northern states but to decrease in southern states, suggesting that the geography of the livestock industry would shift as global warming eventuates. The responses were largely due to temperature and precipitation changes rather than the direct effects of increased atmospheric CO_2.

DS tools are also valuable in helping researchers gain a better understanding of the way complex processes might impact on a grazing system. Traditional competition experiments, for example, tend to be phenomenological, without revealing much about the processes of competition that lead to observed outcomes in real grazing systems. The practical limitations on the size of such experiments limits the number of competitive scenarios that can be investigated. In the current version of GrassGro, for example, the model of competition between companion species in a sward is rudimentary. This limitation has stimulated a combined experimental and modelling approach (T. Bolger, pers. comm.) which is allowing a much wider investigation of species combinations, plant density, spatial arrangements and emergence patterns. The approach should identify the most important factors in competition and allow abstraction to a simpler but more accurate representation for inclusion into future versions of GrassGro.

THE GRAZPLAN EXPERIENCE

The GRAZPLAN group in CSIRO has been involved in research aimed at improving the profitability and sustainability of grazing enterprises through appropriate grazing management for more than 30 years (e.g. Morley et al., 1969; Freer et al., 1994). This research raised the potential efficiency of pasture-based industries in southern Australia, but the potential has rarely been achieved because of difficulty in translating the research into recommendations for individual farms. This difficulty led directly to our development of the generalised computer models of biological processes that are the basis of the GRAZPLAN family of decision support tools. Research modelling has been undertaken by the group since the 1960's (Freer et al., 1970) and DS development has now been under way for a decade (Donnelly et al., 1986). CSIRO has made a long-term commitment to this DS work, without which it would simply not be feasible.

The target audience for the GRAZPLAN DS tools is the technical and advisory professionals servicing the grazing industry in southern Australia. This audience is spread across a wide range of environments. The 28 million ha of improved pastures receive annual rainfalls that vary from 250 to 900 mm, with the pattern of rainfall ranging from strongly winter-dominant through to summer-dominant; soils are equally variable. The grazing industry includes sheep and beef production, often as a dual enterprise, and frequently in combination with cropping. Much research is carried out by CSIRO and by universities, while advisory services are largely carried out by the several State governments. There is therefore no dominant client group on which the development of DS tools can focus. As a consequence, CSIRO has developed DS tools in a way which differs markedly from the "client-driven" approach used by Stuth et al. (1993) and argued for by Clewett et al. (1991). Our "developer-driven" approach has the following distinguishing features:

- The identification of potential DS tools, analysis of their feasibility and their first design and implementation are carried out in-house. A completed product is then marketed to potential users.

- The DS tools generally embody a large amount of knowledge about biophysical processes, expressed as simulation models which are incorporated directly into the computer program. This policy runs counter to that in some other development groups (e.g. Woodruff, 1987), where models are used to develop summary equations or databases which are then incorporated in the DS tool.

We use the full models to summarise the knowledge in a DS tool for several reasons. First, our goal is to produce tools with application across a wide range of environments and animal enterprises. Second, the inherent complexity of grazing enterprises means that simple summaries are not feasible for many problems. This complexity also extends to the management of temperate grazing enterprises, because activities such as buying, selling and mating stock can take place at any time or times during the year.

Hierarchical models and their conceptual basis. To make our DS tools - and hence our biological models - applicable over southern Australia, we had to achieve a high level of generality without sacrificing too much precision or realism (Levins, 1966). The key design strategy has been to structure the models hierarchically (Allen and Starr, 1982). For example the GRAZPLAN ruminant model decomposes the processes of animal nutrition so that each is expressed as a number of equations. The basic equations describe physiological processes, which the model integrates to a higher, whole-animal level of organisation (Figure 1). Furthermore, while the equations may be empirically derived, their form is determined by lower-level, physiological processes wherever these are understood (contra Seligman, 1993); the result is that many of the model's parameters are general for sheep and cattle. Despite its large parameter space, therefore, the GRAZPLAN ruminant model can be initialised easily for a particular breed, and can also be adapted to other ruminants (e.g. red deer; L.W. Partridge, pers. comm.)

If our strategy of building relatively general models is to succeed, it must be founded on a sound conceptualisation of the overall process being modelled. The broad similarity of the various feeding standards (ARC 1980, NRC 1996, SCA 1990) suggests that the science of ruminant nutrition is sufficiently mature to provide a conceptual underpinning for useful models. The same is true for cereal physiology and agronomy, which is why American and European wheat models are so similar in their general structure (Jones and Kiniry, 1986; van Keulen and Seligman, 1987). We believe that a similar conceptual basis is possible for understanding the growth of pasture plants, but that it has not yet been fully expressed. Existing frameworks and models either treat only a single pasture species (e.g. Sheehy et al., 1979), or lack one or more of the following key elements: the phenological cycle, seed and seedling dynamics, uptake and allocation of soil nutrients, or the dynamics of nutritive value. In Figure 2, we propose a general decomposition for the process of pasture growth and decay, based on the structures of several models (Sheehy et al., 1979; Johnson and Parsons, 1985; Hanson et al., 1988; Moore et al., 1997b). The GRAZPLAN group is working to construct a pasture model which fully expresses this decomposition.

Synergies between DS tools. By utilising modular, hierarchically constructed models, our decision support developments are enhanced in two key ways. First, we have been able to proceed incrementally, and release DS tools of increasing power over time (Figure 3). Thus the GrazFeed DS tool, which focuses only on ruminant production, has been followed by GrassGro, which couples pasture and animal dynamics. GrassGro leads on to the GrazPlan DS tool, where the same biophysical models underpin a focus on farm-scale management issues. The second advantage is that by re-using the underlying models, we are able to transfer the credibility of one DS tool to the next. Thus users who are familiar with GrazFeed usually exhibit confidence in the animal production outputs of GrassGro.

Dissemination of "developer driven" DS tools. While a "developer-driven" approach to DS software development has had clear advantages for CSIRO, it also raises difficulties. The most pressing is the need to actively market the DS tools. The GRAZPLAN group has negotiated a contract with a commercial partner to market GrazFeed, MetAccess, GrassGro and GrazPlan. CSIRO retains copyright in the computer programs, while our partner, Horizon Technology Pty Ltd, has sole rights to release compiled versions of the DS tools. This arrangement is effective in terms of CSIRO's objective of disseminating the results of its research. CSIRO also contributes directly to the marketing effort by preparing publicity material, and, most importantly, by conducting workshops to give users familiarity with the DS tools. These workshops also form part of the process of iterative design.

An example of the dissemination of a DS tool in a traditional extension setting comes from the PROGRAZE programme, devised by NSW Agriculture with the aim of training graziers in pasture and animal assessment and in how to use these skills in grazing management. Use of the GrazFeed DS tool was taught as an integral part of PROGRAZE. Because the GrazFeed software provides a way to make use of estimates of pasture mass, the relevance of this skill has now become readily apparent to graziers. The course has reached about 3800 graziers in four years or roughly 15% of all potential clients in Australia's high-rainfall zone and is still continuing.

Representations of management in simulations. Typically, agricultural models treat management through a set of subroutines which handle a fixed set of managerial interventions, e.g. CERES-Maize (Jones and Kiniry, 1986) and GrassGro (Moore et al., 1997b). The individual management activities have much the same relation to the overall model as do submodels such as the soil moisture budget. This approach to simulating management has two related drawbacks:

- the complexity of the model increases and its usability decreases with the number of management activities described;

- users can only explore management activities which have been foreseen by the model authors and programmed into the model.

The GRAZPLAN group has developed a different representation of management activities, based on the approach of Christian et al. (1978). The activities are input as a series of events which are scheduled by a set of rules. In this formulation, a management activity is a property of a biophysical sub-model. For example, instead of writing a paddock rotation manager as a distinct part of our simulation model, we can implement an event which moves animals between paddocks as part of our animal biology model, and then handle any grazing schedule by writing a series of rules which determine when livestock movements will occur. These concepts were used in prototypes of the GrazPlan DS tool to simulate a variety of complicated management systems for the production of large lean lambs described in the next section. Our next step is to link this work with parallel developments for cropping systems (McCown et al., 1996) to create another DS tool, FarmWi$e.

Applications to production and policy issues. The long history of grazing systems modelling has seen a concentration of effort in identifying causes and estimating effects, in an analogy with field experimentation. To improve the output of production systems, it is necessary to shift the emphasis toward predicting future performance of grazing enterprises in different environments, under realistic management and new marketing systems. Predictions will be required for situations where there are no data for model evaluation, and the effects of variation in output (or risk) associated with management options must be assessed. The examples outlined below show just how beneficial this shift in emphasis can be in finally delivering the benefits of much grazing systems research.

Forward contracts to meet market specifications - vertical integration within the grazing industry. Lamb production is a major activity for many graziers in southern Australia; about 1.6 million lambs are slaughtered each year. A shift in consumer preference toward leaner meat has increased demand for larger, leaner lambs. These lambs attract premium prices, but there are considerable risks in finishing them to specification, due to wide fluctuations in the length of the growing season. The GRAZPLAN DS tools were used to assess these risks for the Meat Research Corporation across contrasting climatic regions in south-eastern Australia (Moore et al., 1993). We then undertook further analyses to optimise a production system with a high probability of delivering a specified number of large lean lambs under forward contract, in one region that had been identified as favourable (Moore et al., 1995). McCall et al. (1993) describe a similar analysis to set forward contracts for beef production in New Zealand using the Stockpol model. The emphasis here was to show that variability in pasture growth was a vital element in making decisions to contract supply livestock that meet a tight specification.

Both of these applications aimed to optimise profits under contracts to supply the specified product at different times of the year with a high probability of success. In each, the optimum stocking rate had to be determined under conditions where the expectation of pasture growth was uncertain, only a small price premium was payable for animals meeting specification and price penalties prevailed for animals delivered outside specification. For large lean lambs, the simulations showed that taking contracts was a safe and profitable option as long as a small premium price was available (Moore et al., 1995). For a modest increase in risk (i.e. where the contracts for the larger lambs would not be met in 30% of years), the profit margin could still be doubled, even though lighter lambs produced in poorer years would have to be sold at discount prices. A surprising conclusion was that contracts to deliver lambs at the end of winter were the most profitable, running counter to local district practice and current advice for lamb production systems. For the beef contracts in New Zealand, substantial profit margins were achieved if grain supplements were used to ensure that 90% of cattle committed to forward contracts met the specifications.

These two examples show the potential for well designed DS tools to achieve a better outcome from grazing systems for the producer, the meat processor and the consumer. The DS tools help the producer decide the level of risk faced if a contract is taken to deliver specified livestock on a given date, while the meat processor can use the tool to determine the likelihood of reliable supplies of suitable livestock. The consumer benefits from a more reliable market with much increased quality control for meat products.

Risk analyses. A simulation of a grazing system using long runs of historical weather data can reflect all the extremes in annual production that are associated with fluctuations in weather. The effects of these fluctuations can be modified by management. Risks associated with management strategies can be ranked, for example by the variances of the economic return, and can then be taken into account as well as the average returns. Simpson et al. (1996) showed that for a ewe/lamb system based on either perennial or annual pastures in south-western Victoria, Australia, the perennial system returned more profit with less risk over a two-fold range in stocking rates (Figure 4). Most of the risk to the perennial system was associated with the occurrence of two severe droughts in the 30 years simulated. This approach to analysing risk is most useful for comparing productivity between complex management situations.

On-farm evaluation. Figure 5 shows a simulation of cattle grazing perennial grass-clover pastures on a commercially-managed paddock in Western Australia, drawn from a larger evaluation study (Moore 1996). The GRAZPLAN simulation models are clearly approaching the on-farm realities of this pastoral system. Note also that the rule-based management scheme described above is used to capture the irregular pattern of livestock movements and fodder conservation that actually took place.

Drought assessment. The Australian government has long provided financial assistance to farmers and graziers in times of drought. Recently, this policy has been changed to encourage a greater degree of self-reliance among producers (Drought Policy Review Task Force, 1990); to obtain assistance, farmers must show that their area is experiencing a drought with a 20-25 year return time. In 1995 the GRAZPLAN group was requested by a producer organisation in north-central NSW to carry out an analysis of current pasture production in their region. Over the previous year, rainfall in one part of the area was at the 20th percentile. Long-run simulations with GrassGro, however, suggested that the pattern of rainfall had been unfavourable for pasture growth, so that pasture production over the year had been at about the 1st percentile. The feed drought was much more severe than a rainfall-based assessment had indicated. Use of GrassGro ultimately led to a more rational decision being made in this application of the drought policy (relief was granted).

Emissions of greenhouse gases. The GrassGro DS tool was used to estimate greenhouse gas emissions from native or improved pastures in southern Australia that are used for grazing yearling sheep at a range of stocking rates near the commercial optimum (M. Freer, pers. comm.). On improved pastures, emissions per kilogram of meat produced showed a relatively small increase with stocking rate; on native pastures where increases in stocking rate lead to over-grazing, emissions rose rapidly. The analyses also showed that with total national output of meat held at the same level, greater reliance on improved pasture, particularly in regions of higher potential productivity, would reduce total emissions. Although the benefits seem clear, the impact of such analyses on industry policy for future expansion remains uncertain.

FUTURE OPPORTUNITIES FOR GRAZINGLANDS INFORMATICS

Information technologies have shown explosive growth over the last two decades, but agricultural resource management has been slow to capture the benefits (Donnelly, 1988). DS tools are now helping to redress this, but the current crop of tools are only a beginning. We will limit our discussion of the future opportunities to higher-rainfall systems in developed countries, where we have expertise.

Technical directions. A key technical advance for agricultural DS over the last few years has been a sharp decrease in the cost of developing high-quality user interfaces, largely owing to the rise of

Microsoft Windows™ and the advent of visual programming tools. When coupled with the "library" of models and concepts which is now available from past DS and modelling work, the ability to produce small software packages quickly will be important in supporting learning-oriented extension programmes such as the Property Management Planning courses now under way in most Australian states. Such computer programs would not really be for decision support but more for "learning support," responding to new ways of carrying out extension (Jiggins, 1993). We envisage that they will be put together on demand from pre-existing components, and will not require ongoing maintenance.

This single-issue software will be complemented by the development of modular DS tools which will support studies of new management options and land uses for both producers and policy-makers. These tools will be capable of using models developed by different groups, and it will be possible to configure them to represent the integrated management of a variety of different pastures, animals and crops. The sheer complexity of such integrated systems will require a different approach to using these comprehensive DS tools. Perhaps technical services staffed by experts will emerge; the analogy is with medical services, where general practitioners seek the support of specialist services to assist in making a diagnosis. The technical problems facing graziers in the coming decades will increasingly include issues that impact on other users of land in the same catchment, such as rising water tables and acidification of soils through nutrient leaching. A key challenge for grazing systems biologists in the next decade will be to evaluate and improve existing models of these processes, and to integrate them into DS tools.

What will grassland science make of the Internet? It is too early to tell, but interest among the Australian farming community seems to be strong. The national farmer organisation is currently sponsoring a pilot scheme in which 1000 producers are receiving subsidised Internet services for a year, so the real opportunities should soon emerge. The standard of rural telephone services may be the greatest single constraint on the usefulness of the Internet in the medium term (Buckeridge, 1996). From the perspective of DS tool developers, the Internet will confer the ability to make large databases such as weather and soils information readily available. Once access to the Internet is sufficiently widespread, it will become a low-cost medium for disseminating the kinds of learning-oriented software (and other materials) we outlined earlier. Lastly, the spread of electronic mail will make the developers of DS tools more accessible to their clients - we can expect evaluation of our work to become much more direct and immediate!

Application directions. As our confidence in the underlying models increases, the focus of informatics in grazing lands will shift more and more to the planning of management activities. At the property level, we anticipate greatly increased use of DS tools such as Stockpol, GLA and GrassGro which add a biological dimension to enterprise- or property-level planning and permit ready comparison of management strategies. Figure 6 shows the direction in which this class of tools is evolving. From a user's perspective, the emphasis will be on profits and associated exposure to risk resulting from management decisions. The tools will also provide comprehensive information about off-site impacts such as runoff and leaching of nutrients into streams and groundwater. Users will be able to concentrate on management issues because the tools will make intelligent use of graphical user interfaces, large spatial databases and generic biophysical models. A careful balance between hidden parameters and user-provided information will allow local conditions to be taken into account without requiring excessive inputs at the keyboard.

A number of factors will act together over the coming decades to increase the rate of land use change: a shift from "commodity" production of meat and fibre to products specified for particular consumers, the impact of the global economy, with freer trade and even greater price uncertainties, and the commencement of impacts from anthropogenic climate change. We believe that the state-of-the-art of grasslands simulation has now reached the point which will allow meaningful analyses that can evaluate potential new land uses and production systems before they are tested in the landscape. Thus responses to these external forces can be planned rather than implemented ad hoc. This will place emphasis on modelling tools that are characterised by flexibility of construction, as well as scientific rigour. Lastly, it is vital for new entrants to the grazing industry to be equipped with a systems perspective on the land they hold; the adaptation of the current generation of DS tools for educational purposes is thus another challenging but very important task.

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Figure 2
A decomposition of the processes of pasture growth for management modelling purposes. Not all models will require all elements of this framework. Plant demography has been omitted.

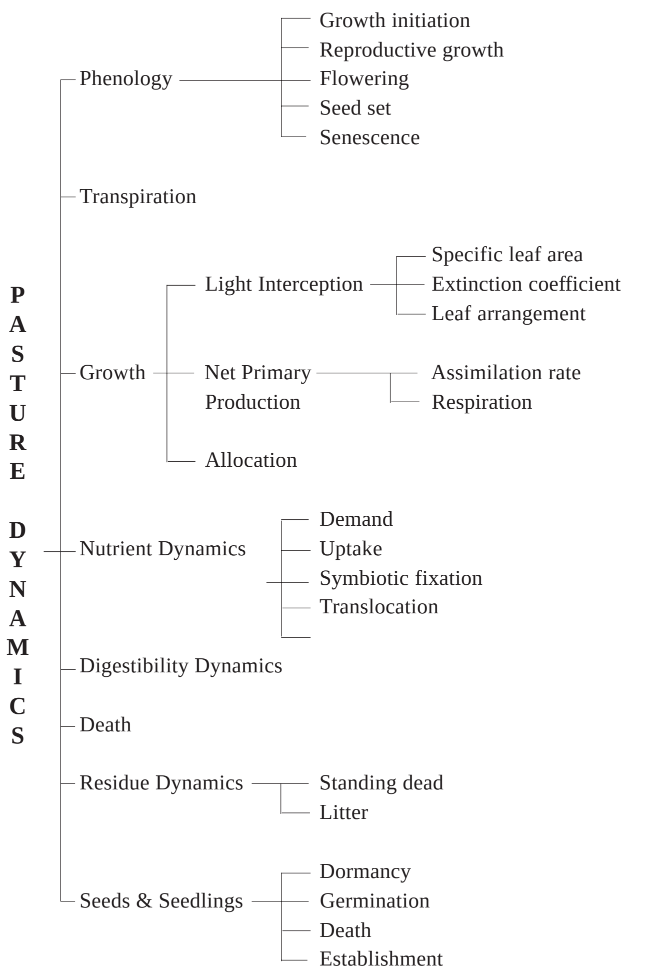

Figure 1
A decomposition of the processes of ruminant biology for management modelling purposes, based mainly on the model of SCA (1990). Not all models will require all elements of this framework.

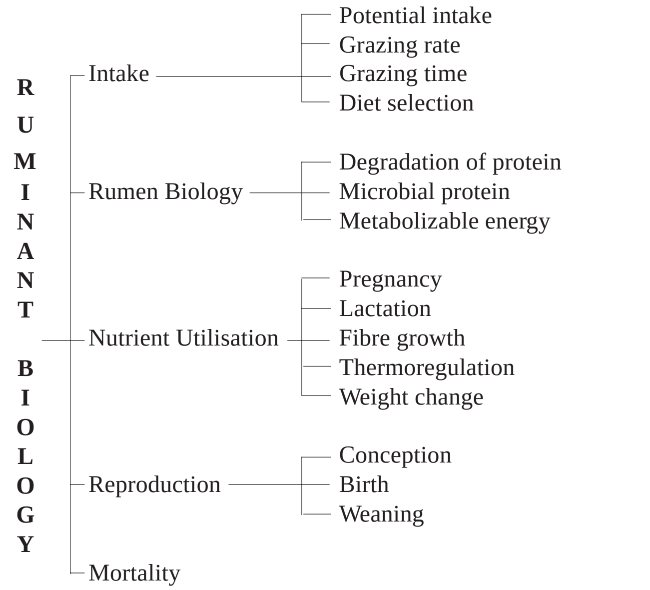

Figure 3
GRAZPLAN - a family of DS tools for the grazing industry comprising MetAccess, a daily weather database, LambAlive, a lamb mortality model, GrazFeed an applicataion of feeding standards to grazing ruminants, GrassGro, an enterprise-scale pasture and animal production model and GrazPlan, a whole farm model for the strategic management of grazing systems (After Donnelly et al., 1997.)

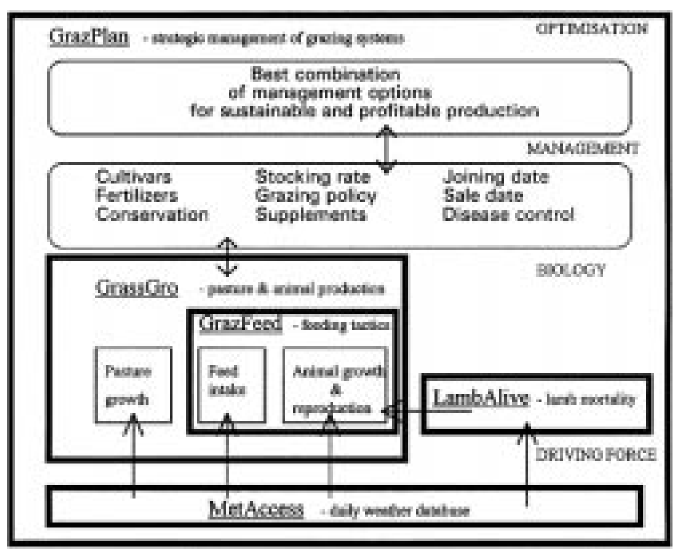

Figure 4
Risk analysis with the GrassGro DS tool. Predicted annual gross margins per hectare and their standard deviations for a crossbred ewe-lamb enterprise, at a range of stocking rates (ewes per hectare) and based on either annual grass-subterranean clover or perennial ryegrass-subterranean clover pastures grown at Hamilton, Victoria.

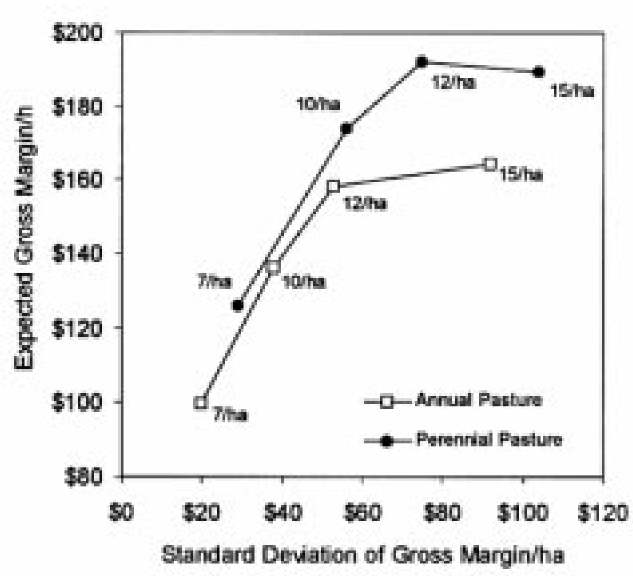

Figure 5
An on-farm evaluation of the GRAZPLAN pasture and animal bilogy models from a commercially managed paddock near Busselton, Western Australia (Moore, 1996). Continuous lines denote simulated values; squares and dashed lines denote measured values. Vertical bars on measured pasture values show standard errors of the mean. A rule-based management system was used to handle hay cuts and the stocking and destocking of the paddock at irregular intervals.

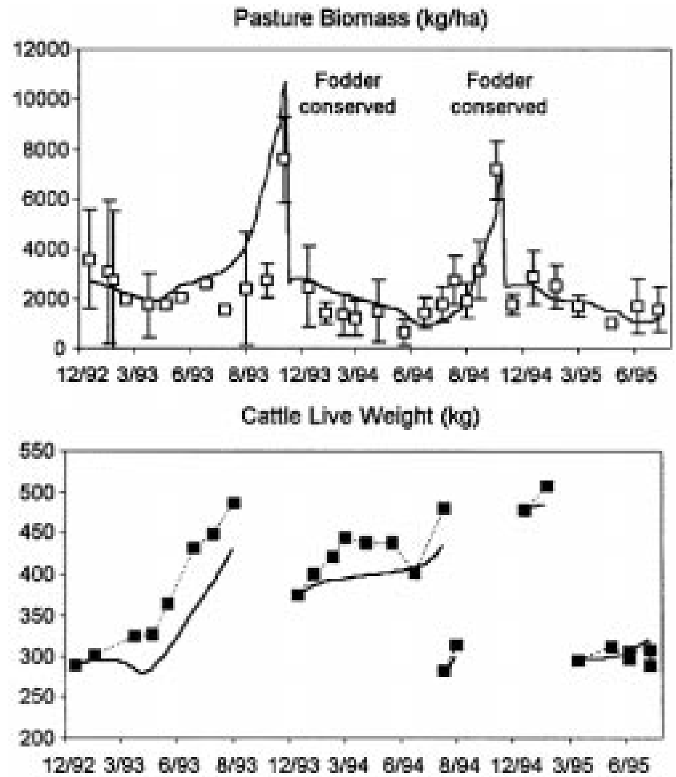

Figure 6
Components of an idealised grassland management DS tool, based largely on GrassGro (Moore et al., 1997b). Generality of application is achieved by the use of hierarchically designed process models. User inputs are kept to a small number of readily measurable items, by the use of centrally compiled data bases and pre-packaged parameter sets for the various component models. Consequently, users' attention can be focussed on management issues.