CONTRACT REVIEW

SUSTAINABLE GRAZING SYSTEMS FOR FARMS IN TEMPERATE AUSTRALIA

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INTRODUCTION

If grazing systems are to be sustainable they must be profitable. It is unrealistic to consider sustainability solely in terms of resource conservation without identifying the key profit drivers and adopting a sensible approach to risk management. A grazing enterprise may also be only one of several enterprises on a farm and its integration into a whole-farm management plan is an essential step in achieving long-term sustainability. Likewise, each farm is only one of the land-use components in a catchment or district. Apart from economic realities, sustainable grazing systems must be built on sound biophysical and ecological principles and they must be socially acceptable. In this contract we discuss first well-established ways to increase profitability without substantial increases in costs and illustrate how modern decision support (DS) tools can help to provide better assessment of risks and opportunities. This is followed by a discussion of some of the main ecological and biophysical processes driving farm-level grazing systems in temperate Australia where we believe more research is required. These include issues of species persistence and compositional changes in pastures, nutrient cycling and maintenance of stable water tables as they interact with grazing systems.

The grazing enterprise as a sustainable business

Resource management for long-term production in grazing enterprises is a difficult and sometimes risky business. Graziers may perceive that they are not in a financial position to afford management practices compatible with wise land use and resource conservation. Rural lands have been damaged by years of inappropriate management and the scars are increasingly visible. Poorly productive pastures are widespread, with legumes and perennial grasses, both sown and native, being replaced by weeds or less productive annual grasses. Declining soil fertility and soil structure and damage from soil acidification and salinisation may be irreversible or extremely expensive to remedy. More than 30 million ha of farmland in the better-watered regions of Australia are now highly acidic and options for growing some valuable crop and pasture species are limited. A further 55 million ha are at risk due to increasing soil acidification. Current loss of national productivity due to soil acidity is estimated at \$300 million and to salinity at \$200 million. Overall, annual losses from all sources of land degradation are estimated to exceed \$1 billion (Chartres and Isbell 1995). There is also the loss of biodiversity in our unique native flora and fauna. Other costs that reduce financial sustainability are associated with inappropriate management such as sub-optimal stocking rates coupled with unecessary supplementary feeding of livestock.

The magnitude of these losses, and the potential size of the impending environmental disaster if no action is taken, have stimulated several thousand Landcare and similar groups to initiate remedial action to rehabilitate degraded land and soils. Less success has been achieved in applying existing knowledge from research which can dramatically increase profits and place graziers in a sound position to invest in better land care and complement Landcare activities. For example, even with current depressed wool prices, profits on a typical 550 ha sheep farm in southern temperate Australia can be increased from a current average loss of \$22,000/year to a profit of \$68,600/year (Lean 1997). It is urgent that graziers become aware of these significant possibilities for the sustainability of their businesses. One approach which will help is to provide graziers with a comprehensive assessment of the relative importance of financial, biological and environmental risks that affect production in their own enterprises.

Profit drivers for sustainable grazing systems

Current farming practices clearly need adjustment if Australia is to have an agricultural sector that is capable of meeting the competitive markets of the 21st century. The processes that lead to land degradation need to be understood so that effective remedial action can be taken, but landholders must be in a sound financial position with survival no longer their immediate concern. Sustainability is as much about profitability and cash flow as it is about resource conservation. The landholder therefore needs to identify the key profit drivers, which for most temperate grazing enterprises are well researched. Joining at a time that achieves the best balance between the seasonal pattern of pasture supply, animal needs and market prices, and minimising supplementary feeding, cost almost nothing to implement and can result in immediate savings. However, it is through increasing stocking rates on productive pastures that the biggest financial benefits are most likely. Extensive research over several decades shows that stocking rate is the key profit driver and unless it is close to optimum, other management tactics may have little impact on profits. Stocking rate is also a key driver of ecological sustainability in a grazing system. If stocking rates are too high then exposure to environmental damage as well as financial losses becomes inevitable. The issue then is: what is the optimum sustainable stocking rate for any grazing situation?

Estimating sustainable stocking rates

Serious depletion of ground cover for prolonged periods is a sure indicator that stocking rates are too high. However, critical levels of ground cover will vary widely with soil, pasture type and fertiliser policy and many native perennial grasses are susceptible to intense and prolonged defoliation. Simulation provides a powerful way to explore likely responses of a grazing system to a range of management options such as stocking rate, although there are limited experimental data to test the outcomes. The CSIRO GrassGro DS tool (Moore *et al*. 1997) is ideal for this purpose as it simulates pasture and animal production on local soil types using relevant weather records as the driving variables. It thus links sustainability and profit for a specific grazing enterprise to the local environment. Interactions between management variables can be explored efficiently and quickly, but user training is essential for effective use.

FINANCIAL STABILITY OF GRAZING SYSTEMS

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Stocking rate and financial risk

The need to generate profits without exposure to unacceptable levels of financial risk is fundamental to the sustainability of grazing systems. Stocking rate is a key profit driver and gross margins (GM) generally increase with stocking rate up to a point beyond which further stocking rate increases have only a marginal impact on profits. More extreme increases in stocking rate will lead to a rapid decline in GM and can result in environmental degradation. In selecting a sustainable optimum, however, variability in annual GM is just as important as the actual level of the GM itself.

The examples outlined below are derived from simulations with GrassGro of three Merino wether wool production enterprises in south-eastern Australia, located on sites with low, moderate or high soil fertility. The pastures were based on annual grass and were continuously grazed. The period simulated was for 27 years from 1970. Figure 1a illustrates the relationship between financial risk and GM as stocking rates increase at three levels of soil fertility in otherwise identical conditions. GM increases with stocking rate but the variability in GM (measured here as the standard deviation (sd) of the GM) or financial risk increases more rapidly when fertility is lower. This is shown more clearly in Figure 1b at the site of low fertility, where the simulation has been extend to 100 years from 1897. The annual estimates of the simulated GM at each stocking rate (10, 15, 20 and 25 wethers/ha), presented as boxplots, illustrate the extent of annual variability. The bar within the boxes represents the median GM. The bottom of the box is at the 25th percentile and the top at the 75th percentile. The lines extending from the box include the remaining data but with outliers indicated as dots. The length of each box and associated lines and dots directly represent the financial risk associated with each stocking rate. It is clear that risk is slight at 10/ha but the median GM is also small. GM increases by 70% at 15/ha for a small increase in risk, but risk increases substantially at 20/ha for no further increase in GM. At 25/ha GM has fallen and the chance of making a negative GM is greater than one year in four (25% of the GM values are below the bottom of the rectangle ie, a GM of less than -$40).

The simulations show that the main reason for the down-side variation in annual GM at each stocking rate was the need to feed relatively expensive supplements (oats at $150/t) when forage was scarce, particularly during major droughts, but also during shorter dry spells which occurred more frequently. Even so, the rule for feeding supplements was aimed merely at keeping the animals above condition score one to avoid deaths. No other feeding was specified. The up-side variation is smaller and was due to year-to-year fluctuations in production per head and product quality and insufficient animals to use extra feed grown in the better years.

At low stocking rates, the simulated forage available from pastures was usually well in excess of animal needs, except in severe drought years. The need for supplements was therefore minimal and the range in GM was small (Figure 1b). At very high stocking rates, production per head was generally lower, and in most years, forage supply from pasture was inadequate; substantial and costly supplementary feeding was necessary to keep animals alive. The increase in up-side variation at 25 sheep/ha was due to livestock numbers sufficient to utilise all the feed grown in very good years.

Two other features in Figure 1 deserve comment in relation to sustainability. First is the importance of recognising that an over-cautious attitude to risk will lead to greatly diminished GM. The ability to invest in improvements that may lead to better sustainability is therefore reduced. The second issue is the financial response at sites with different soil fertility. It is interesting to note that current research indicates the possibility that very much higher herbage production may be practicable through heavy application of P fertiliser (Cayley and Hannah 1995). This would result in a significant shift in the curvilinear relationship towards the much higher stocking rates shown in Figure 1a.

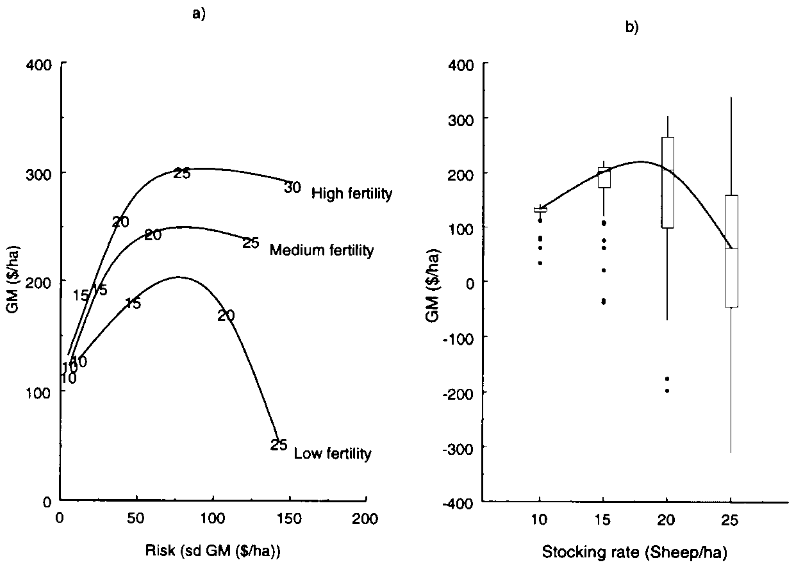

Figure 1. (a) Gross margin (GM) for wool production *v* financial risk or variability in annual gross margin (s.d. GM) with stocking rate (sheep per ha) for low, medium and high fertility. (b) The increase in financial risk as stocking rate increases at the site with low fertility. The curve in (b) is plotted through the median GM for each

Assessing the probability of the need for supplements in drought or dryspells

When a dry spell starts, farmers are faced with tactical decisions such as to feed, to sell, or to agist. Which decision they take will depend on their assessment of the probable length of the dry spell. As we have discussed, feed costs are a significant determinant of the variability in GM and hence the financial sustainability of the system. GrassGro can be used as a tactical tool to assess the probability of herbage supplies exceeding specified amounts over a short period ahead of the current date (up to one year). Two case studies presented below outline how this is done.

The first study was carried out at Yass in August 1997 after a very dry winter. To prevent losses associated with nutritional problems during pregnancy, Merino ewes had been fed a supplement to keep body condition score above two. On 10 August the ewes were due to start lambing but the available green pasture was only about 500 kg DM/ha. The management issue on the 10 August, was therefore a tactical one about stocking and feeding decisions that will influence the flock situation at the start of next growing season, *ie* winter 1998. GrassGro was used to simulate pasture and animal production, starting with the situation of the pastures and flock on 10 August 1997, forward to 31 May 1998 using the daily weather records for the period 10 August - 31 May for each year from 1970 to 1995. These simulations also provide estimates of feed costs from which a cumulative probability distribution was calculated (Figure 2).

Figure 2 shows the distribution for the 25 years of simulated feed costs over the nine month period from 10 August for sites with low and high soil fertility. Any figure read from the Y-axis is the probability that the total feed cost over this period will be at least the corresponding amount on the X-axis. For example, there is a 50% probability that the feed cost will be at least \$20/ha at the high fertility site or \$60/ha at the low fertility site.

The spread in feed costs shown in Figure 2 reflects the range in costs encountered from wetter to drier conditions during the period August to May over the 25 years. Over the whole range there is a substantial difference in the probability distributions between the 2 sites. The reduction in feed costs associated with regular fertiliser use is at least as great in drier years as in wetter years and will lead to a reduction in financial risk. This was of course, one of the main factors contributing to the risk differences shown in Figure 1a. While no analyses can predict the future for the grazier, this analysis does provide a quantitative estimate for a particular farm of the feed costs likely to be incurred for any specified level of risk.

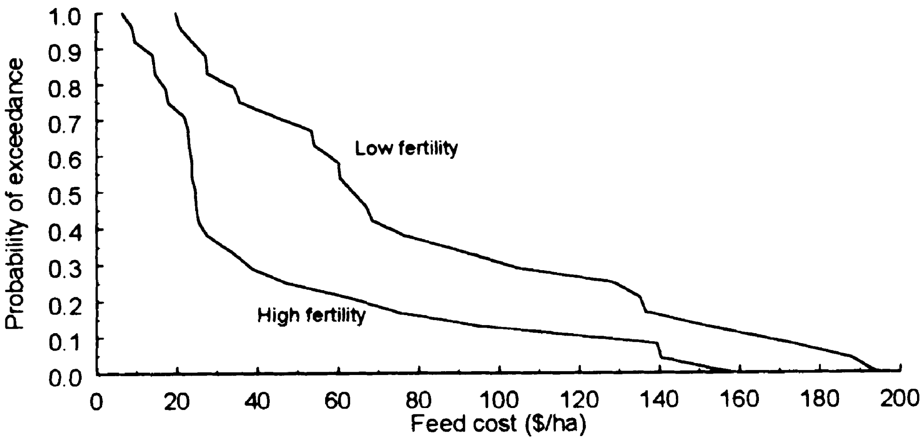

Figure 2. The probability that the feed cost will exceed specified levels

The second case study is based on analysis of seasonal grazing outlook at the Pastoral and Veterinary Institute, Hamilton, Victoria, following the dry growing season in 1997 when only 67% of average rainfall fell in the March-October period. At the end of October, measured total available herbage was 2.3 t DM/ha on perennial ryegrass pastures stocked at 15/ha with Merino ewes and their lambs. The expected daily availability of herbage DM for the period November to April, based on simulations of these pastures over the past 100 years, is shown in Figure 3a. In 50% of years, peak available herbage DM exceeds 5 t/ha and exceeds 7 t/ha in 10% of years. However, in 10% of years peak available herbage does not exceed 4 t/ha.

Figure 3b shows the expected availability of herbage between November and April given the very low DM (2.3 t/ha) and soil moisture present at the end of October 1997. These tactical simulations suggest that feed availability in the summer-autumn period is likely to be sparse. This means that there is an increased

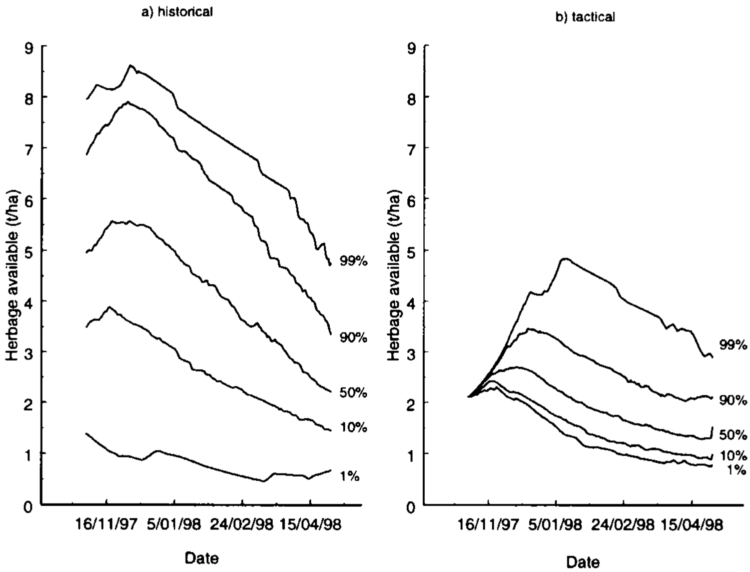

Figure 3. Percentiles for herbage availability (t DM/ha) over six months from November to April from a) historical simulations and b) tactical simulations where the situation prevailing on 1 November 1997 was taken as the starting condition. In the historical simulations the period simulated was continuous from 1879 until 1997. In the tactical simulations historical weather data for the period November to March each year from 1879 until 1996 were used.

likelihood that some supplements will need to be fed in the late summer or autumn. The tactical simulations suggest that at high stocking rates and given the conditions prevailing at the end of October 1997, there is about a 2 in 3 chance that at least 8 kg of supplement will be required per ewe to maintain body condition score at 2. This compares with at least 26 kg of supplement required over the same period in the worst 4% of years since 1879. The analysis here suggests that even with the dry winter and the expectation of less than normal forage over summer and autumn, maintaining a stocking rate of 15 ewes/ha is likely to be financially sustainable.

These case studies are just a few examples of the power of current DS tools to couple the mass of accumulated weather records to our scientific knowledge of grazing systems, in the interests of long-term sustainability.

ECOLOGICAL SUSTAINABILITY - SPECIES PERSISTENCE IN GRAZING SYSTEMS

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General concepts of stability and change in pastures

One of the cornerstones of sustainable grazing systems is a relatively stable composition of productive and nutritious species in the pasture plant community. Why do some pastures remain stable and productive while others are unstable and become degraded? What steps must be taken to improve the productivity, sustainability and stability of these pastures? A framework of ecological concepts relating to stability and change in pasture species composition is needed to develop our understanding of botanical change, so that we can better manage our pasture resources.

Stability can be defined as the degree to which a pasture community resists change when disturbed by management actions or natural phenomena such as climate. The stability of a pasture therefore is related to its ability to return to its original state after being disturbed. Traditional models of succession in plant communities suppose a single, stable state for the pasture in the absence of disturbance, termed the climax, which it steadily moves towards after any disturbance. Contemporary ecological models of vegetation change, such as the 'State and Transition' model (Westoby *et al.* 1989), suggest a more dynamic situation where change does not necessarily move in a single direction. In this model, if a disturbance exceeds the limits of the stability of the pasture, then the pasture does not return to its original state after the disturbance, but rather crosses a threshold and reaches some new state. Transitions between states are triggered by natural events or management actions or a combination of the two.

Plants, animals, soil, climate and management all interact to determine the state of a pasture, and how stable that state will be. For example, perennial grasslands are generally considered to have good stability. However, in environments with strongly seasonal rainfall, perennial grasslands have been converted to annual graslands by grazing (Heady 1958). When grazing is stopped, they often do not revert to perennial grass dominance (Hutchinson 1992). Unfortunately, it is easier to move from a stable, productive pasture to a degraded pasture than in the opposite direction. Some extreme events such as drought, especially when combined with heavy grazing, can result in rapid deterioration of the composition of a pasture (Hutchinson 1992). In contrast, improving the composition of a pasture with grazing management, where possible, is generally only successful if continued for a relatively long period of time. To apply these concepts to maintaining or developing stable, sustainable pastures, we must understand how a stable community is forced across a threshold into a less stable state, and how this change can be reversed.

Why pasture systems are sometimes not sustainable

Pasture improvement in Australia has generally been based on 'replacement' philosophy (Whalley and Lodge 1987) and the assumption that sown pastures, once established, are effectively permanent. However, there are several flaws in this philosophy, which are highlighted by surveys, farmer observations and limited research. For example, Garden *et al.* (1993) found that many pastures previously sown to introduced species were dominated by either annual grasses or native perennial grasses. The reasons for this decline in introduced species are likely to be a combination of unsuitable soils, poor establishment, insufficient fertiliser, selective grazing, drought and poor management (Hutchinson 1992).

Simpson and Langford (1996) have highlighted the problem of attempting to establish introduced species on soils which are inherently unsuitable, mainly because of shallow soil, acidity and low fertility. They recommend a more discriminatory approach to property development, with careful consideration of site and livestock requirements in selecting appropriate species. Alternatively, areas which are considered inappropriate for sown species can be managed on a long-term basis using lower inputs of fertiliser and legume seed. Pastures in these areas may contain a mixture of native perennial grasses, volunteer annual grasses and remnants of previously sown grasses and legumes. Since 8-10 years are required to recover establishment costs of sown pastures, pastures cannot be economically sustainable unless they survive beyond the pay-back period. The wisdom of applying the same technology across the whole of a property therefore needs to be questioned. There is also a need to balance productivity and the maintenance of ground cover to prevent erosion and other forms of land degradation. In many situations, this may mean utilising existing pastures containing native species rather than sowing poorly adapted introduced species.

Fertiliser is usually applied when pastures are sown, and follow-up fertiliser applications are recommended. However, the low profitability of many grazing enterprises means that some pastures must survive without regular fertiliser inputs. Such pastures may continue to grow for some years by 'mining' nutrients from previous applications, but the point is eventually reached where many sown species are unable to compete with species which are able to survive at lower fertility levels. If sown perennial grasses decline, their place is often taken by less productive annual grasses, creating a pasture composition which is inherently less stable and difficult to return to its previous state. In some cases, previously-sown pastures may be reinvaded by well-adapted native species which form a pasture which is stable and productive under a wide range of conditions (Garden *et al.* 1993).

An example of the interacting effects of drought and management on pasture decline, even under high fertility conditions, has been described by Hutchinson (1992). Over a period of 28 years (including the droughts of 1965 and 1980-82), a phalaris/clover pasture on the northern tablelands of NSW was relatively stable at a low stocking rate, but at stocking rates above 15 sheep/ha, the proportion of phalaris relative to annual grasses declined. Both theoretical and experimental evidence suggest that the closer a pasture is pushed towards maximum productivity the closer it is to the limits of its stability, and therefore more vulnerable to environmental fluctuation pushing it across a threshold to a degraded state (Noy-Meir 1975). A somewhat lower stocking rate will ensure a more stable pasture with less critical management requirements for sustainability, but with somewhat lower production, at least in the short term. This highlights the need to reconcile ecological stability and vulnerability with long- and short-term profitability and risk.

Sustainable grazing systems can only be achieved by careful consideration of animal requirements, land capability, species choice, fertiliser inputs and appropriate management, including drought strategies. For ecological sustainability, the goal of management is to seize opportunities for favourable transitions and evade hazards which threaten unfavourable transitions (Westoby *et al.* 1989). Only then can a land manager ensure that pasture composition will not move from a stable to an unstable state, where production may be significantly lower, and from where it may be difficult to return.

WATER LOSS FROM GRAZING SYSTEMS

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Water balance of land under pasture

Winter rainfall is in excess of evapotranspiration (ET) over much of the temperate grazing lands of southern Australia where surplus water must be either stored in the soil or contribute to run-off. Movement of water beyond the root zone of pastures may leach nutrients and cause soil acidification and ultimately pollution of waterways. It may also cause water tables to rise, bringing salt into the upper soil profile. Under the original native trees and deep-rooted shrubs, most of the annual rainfall was used by the plants so this deep drainage occurred infrequently, usually only in very wet years. With clearing and pasture improvement, replacement of the natural vegetation with shallow-rooted annual grasses and legumes has removed a safety buffer which protected the soil and groundwater environment. Managing annual pastures for high productivity results in only a marginal increase in total water use, the main effect being increased plant transpiration of water at the expense of soil evaporation (Bolger *et al.* 1993). There is now growing interest in exploiting the potential that deep-rooted perennial pasture species offer to redress the serious environmental damage that is occurring. If the perennial species can use water at depth, a solution may be available to control water balances which would help to ensure profitable production and to secure more sustainable grazing systems in the longer term. However, the impact on profitability and the role of grazing management to achieve the potential benefits need to be established. The simulation study described below (Bond *et al.* 1997) was undertaken for the MRC Sustainable Grazing Systems Key Program (Mason and Andrew 1998) to do this and to predict likely water-balance responses to grazing management at field sites at Hamilton, Albany and Tamworth. Although the results are expected to be indicative, this study was exploratory in nature and undertaken with minimal input data and with no opportunity for validation.

The simulations were made using GrassGro (Moore *et al.* 1997) to predict pasture responses to grazing management on specified soils based on long-term (25 years) meteorological records from each site. The water balances were calculated using SWIMv2 (Verburg *et al.* 1996), running in the APSIM (McCown *et al.* 1996) modelling shell, and with the pasture growth profiles predicted for each pasture species by GrassGro. The pasture, animal and water balance models used the same climate file to drive the simulations. Demonstrating our ability to link outputs from the two simulation systems was a requirement of MRC. Table 1 provides a brief summary of the results for the main treatments tested in the simulations.

Table 1. Simulated annual waterbalance (mm) for different pasture types at three locations based on rainfall, evapotranspiration (ET), drainage (D) and runoff (RO)

Pasture	Hamilton				Albany				Tamworth			
type	Rain	ET	D	RO	Rain	ET	D	RO	Rain	ET	D	RO
Annual	713	440	195	6	693	483	206	0	708	-	-	-
Perennial		528	109	5		554	139	0		674	3	27
Native		-	-	-		-	-	-		659	25	21
Woodlot		630	13	5		694	5	0		699	0	11

At Albany and Hamilton, predicted drainage of water below the root zone of pastures was substantial. However, the simulated perennial pastures reduced deep drainage by about 100 mm compared with drainage from annual pastures, a result similar to that from an experiment at a site with similar rainfall near Rutherglen, Victoria (Ridley *et al*. 1997). At both sites, trees in a woodlot were much more effective in reducing drainage to near zero. At Tamworth, the simulations suggested that deep drainage was less likely and in terms of water balance, pasture-based enterprises appeared to be sustainable. On average, the pastures at Tamworth were able to exploit all available soil water as there is a less than 50% probability of rainfall exceeding potential ET in any month. There may be less need for trees to limit deep drainage in this environment.

In southern Australia, where much of the rainfall occurs in winter, perennial pasture species although better than annual species, still did not capture all the water draining from the system. The study indicated that other deep-rooted vegetation such as trees will be needed in these environments with wet winters. The major issue that needs resolution is how much and where this vegetation should be sited in the farm landscape and what impact it will have on the physical and financial sustainability of the grazing enterprise. This contrasts with areas in northern NSW with summer-dominant rainfall, where pastures based on introduced or native perennial grasses can maintain a better water balance because of the temporal distribution of rainfall in the region.

Sustainable production and profit

In the simulations at Hamilton, perennial pastures were more profitable than annual pastures, at least in the short-term as this was compatible with incremental gains in reducing deep drainage. However, an issue emerging from discussion of these results from Hamilton was the persistence of deep-rooted perennial species. At Albany, the perennial grasses kikuyu and tall fescue have contrasting growth patterns to the winter-active annual grasses and have potential to contribute to a more uniform supply of feed throughout the year. These species are not commonly used and management guidelines for their inclusion in pastures are required. Pasture growth at Tamworth was more variable between years than at the southern sites. Phalaris-based pastures might be slightly more profitable than pastures based on native perennial grasses, although the latter were predicted to be more responsive to sporadic rains.

The simulation study showed that a simple assessment of average rainfall and potential ET coupled with an estimate of the capacity of the soil to store moisture would be a useful indicator of the hydrological sustainability of a grazing enterprise in a given environment. Pasture alone is unlikely to achieve a satisfactory water balance in wetter predominantly winter-rainfall areas. Although stocking rate was a key profit driver in all grazing systems studied, the simulations showed that it and other grazing management practices such as seasonal pasture spelling were unlikely to have an important impact on water balance, which accords with experimental results (T.P. Bolger unpublished data). These observations indicate the need to develop strategies for including other deep-rooted vegetation in our grazing lands on farms in southern Australia.

EFFICIENT NUTRIENT USE

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Grazing enterprises in southern Australia face a number of significant soil nutrient-related issues that reduce profits and threaten sustainability. The tacit exploitation of nutrient cycles, for example, is a key contributor to the present high rates of soil acidification. It is estimated that 50-60% of acid inputs to clover-based pasture systems are related to product removal (C-cycle) and 40-50% to leaching of nitrate (N-cycle) from soil (Ridley *et al.* 1990). Phosphorus (P) loss in runoff from pastures is also emerging as a major issue for graziers because of its impact on surface water quality (Wasson *et al*. 1996). Concentrations of P in runoff are usually highly variable, but moderate to very high levels have been recorded following storm events. Despite these concerns, P deficiency is widespread and undoubtedly constrains pasture production (MacLaren *et al.* 1996) and contributes to "declining" or poor botanical composition of pastures (Saul 1997). In addition to P deficiency, N deficiency is widespread and deficiencies of sulphur (S), potassium and certain micronutrients are common, depending on soil type. In most soils, application of some P is essential for establishment and maintenance of clover in pastures, and consequently also for input of N to the grazing system (*eg* Lazenby 1976).

Despite the importance of soil fertility for high production, fertiliser use is subject to considerable vagary and even confusion. This is partly because P fertiliser is a major annual discretionary cost for graziers and its use is very sensitive to their terms of trade. For example in Victoria, McLaughlin (1992) estimated that greater than 80% of pastures in the 1950s were fertilised annually with ~12-15 kg P/ha, but by 1990 probably only 20-40% of pastures received an annual dressing of ~10-12 kg P/ha. Given that recent split-paddock trials confirm that P fertiliser use generally remains profitable (*eg* Saul 1997), why have graziers reduced their use of P fertilisers and accepted lower potential production and poor pasture quality? Explanations may include misinterpretation of soil fertility tests or indeed failure to use them. Improvements in soil fertility must be accompanied by increased stocking rates to ensure that any extra pasture grown is utilised, otherwise most of the investment in P fertiliser is wasted (*eg* Cayley 1991). Unfortunately, soil fertility advice is rarely accompanied by grazing management advice and *vice versa*.

Perhaps we should not be surprised at the changes in fertiliser practice which have occurred. Because stocking rates have remained conservative it is unlikely that graziers would see a disadvantage from reducing their investment in P fertiliser. In fact, if pastures are under-utilised, the fastest way to increase profitability in the short-term can be to reduce fertiliser costs (Cayley 1991).

There is presently a resurgence of interest in better soil-fertility management. Grazier-initiated trials in south-eastern Australia have focussed on the need for a systems approach for managing soil fertility (de Fégely 1997). The work has attempted to establish guidelines for determining potential carrying capacity and the fertiliser rates needed to maintain high stocking rates (Saul 1997). However, there is little doubt that the industry has been slow in promoting a systems approach to fertility management.

Progress in modelling nutrient cycling under pasture systems

The limited number of computer models developed to assist fertiliser decisions for Australian pastures fall into two categories. First, tools to assist decisions about how much fertiliser to apply in the current year eg, Superate; Decide (Bennett and Bowden, 1976) and second, models of nutrient cycling. The potential of the latter modelling approach was shown by Blair *et al.* (1976), who constructed one of the first P-cycling models for pasture systems. They examined the impact of more nutrient-efficient pasture species, predicted the efficacy of low-solubility P fertilisers [the accuracy of their predictions compares favourably with findings from a recent national trial of reactive phosphate rock (Sale *et al.* 1998)], examined the effect of P losses to animal camps, and the consequences of ceasing P applications. Our own analyses of soil-fertility management using GrassGro, with its rudimentary model of pasture fertility, indicate the value of maintaining high soil fertility during drought. This fundamentally challenges current fertiliser practice in dry years (Figure 2).

We are constructing NutriAce, a model of soil fertility to manage C, N, P and S cycling in grazed pastures and assist productive, profitable and environmentally-acceptable management of grazing systems. It is based on the earlier soil nutrient-cycling model of McCaskill and Blair (1990) and the pasture and animal models used in GrassGro, modified to account for nutrient fluxes. This will form the basis of a future DS tool for graziers. The approach enables the complexity of the whole biological system to be accommodated in decision making, allows tests of long-term production and sustainability goals and allows the physical and financial outputs from grazing systems (and attendant measures of risk) to be estimated.

Testing components of NutriAce

As part of the development of NutriAce, we have been empirically testing model predictions of the intake and excretion of N and P by grazing ruminants and consequently the impact of livestock on nutrient cycles. To do this, diet selection and nutrient transactions in the ruminant must be calculated. It is important in describing nutrient cycles to know the chemical form of nutrient intake and excretion, and the partitioning of excreted nutrients between urine and faeces.

Until recently, techniques for estimating diet composition and herbage intake by animals were not accurate enough to allow estimates of nutrient inputs from different sward components. Moreover, urinary nutrient returns were difficult to estimate without resorting to total urine collections. We have combined alkane-based procedures (Dove and Simpson 1997a) to estimate N intakes and faecal N excretion by sheep grazing at Wagga Wagga in south-east Australia, with the GrazFeed DS tool (Freer *et al.* 1997) to estimate total N return and its partitioning between urine and faeces. In brief, it was estimated that sheep grazing annual or perennial grass-based pastures at 10 dse/ha, consume and return about 120 kg N/ha/year. This is similar in magnitude to the amount of N fixed by pasture legumes in a year. Estimated (alkane method) and predicted (GrazFeed) intakes of herbage and of N agreed well and predicted urinary N excretion was closely related to N intake (Dove and Simpson 1997a).

Similarly, P intakes and faecal P returns were estimated from a knowledge of the P content of the individual plant species consumed, the estimated faecal output and the P content of faeces (Dove and Simpson 1997b). We estimated that about 12 kg P/ha/year would be redistributed by sheep grazing at 10 dse/ha. This is similar in amount to the P applied as superphosphate at standard application rates. The P content of the consumed diet was similar in winter and spring, but markedly lower in summer. However, the relationships between the apparent absorption of P and P intake appeared to differ between seasons. The results indicate that it is not possible to assume a simple relationship between P intake, P absorption and P excretion. Distinct seasonal relationships between P intake, retention and faecal excretion are probably a result of interactions between herbage P concentration, the digestibility of the consumed diet and ME intake.

These results raise issues of importance for nutrient-cycling research. The combined use of field experimentation, modelling and the use of models as 'measurement devices' is a potent route towards improved understanding of nutrient cycling in grazing systems. For the moment, the use of nutritional models such as GrazFeed to predict urinary and faecal excretion has been restricted to work on N cycling but, in principle, there is no reason this could not be extended to other nutrients. There appears a disjunct in published work on P kinetics in grazing livestock, between studies in which urinary P excretion does not feature as an important component of the P cycle (eg, Barrow and Lambourne 1962) and studies which demonstrate that both in sheep and cattle, urinary P excretion can assume significance as a component of the cycle whenever animals are gaining weight and thus are in positive P balance (Ternouth *et al*. 1996). This may reflect the fact that early studies were conducted with penned animals at maintenance. Whatever the reason, there can be no doubt that in modelling P-cycling in grazing systems, allowance for urinary P excretion must be included.

Conclusion

The solution to some of the nutritional problems on grazing lands will probably come from a greater protection of riparian zones, wider use of deep-rooted perennials in pastures and the strategic use of trees or other deep-rooted vegetation in landscapes. An issue not being discussed widely in Australia is whether agriculture should be intensive and affecting only a small part of the landscape or based on low inputs and extensive. We contend that the models of agricultural systems being developed now will have an important place in the assessment of the practicality of change to grazing systems in physical, financial and environmental terms. Most importantly there are DS tools available now, such as GrazFeed and GrassGro discussed earlier in this Contract, that can be used to set benchmarks and to calculate the risks to profitable and sustainable production for districts or for individual farms.

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