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PERENNIAL PASTURE MANAGEMENT:

How plant physiology can help us achieve better grazing management.

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Summary: Plant physiologists have developed a broad understanding of how plants function and how they contribute to yield in pastures. Historically, that knowledge has been crucial to a number of the many significant advances in the agronomic management of pastures in Australia. However, plant physiology has been slow to contribute to better grazing management. This has not been for want of trying, but has been due to insufficient consideration of all facets of the grazing system. The size and complexity of this task is daunting and it has defeated real progress for many years. Modern technology, in the form of the computer-based decision support system, is now allowing the science of pasture plant physiology, animal behaviour and animal physiology to be integrated in the analysis of grazing systems. These tools offer novel and objective support for the complex decisions that graziers make when managing the grazing of pastures for profit and sustainable production.

Understanding the physiology of pasture growth -an historical perspective

What is plant physiology?

Plant physiology is the study of how plants function. This includes research into how plants capture the energy in sunlight and use it to manufacture sugars (photosynthesis), how plants take up water and nutrients from soil, and what drives plant growth. Plant physiological knowledge is usually put into practice by agronomists who deal with the physiology of plants grown as crops or pastures.

Plant physiologists and agronomists have long been interested in using knowledge of the science of pasture growth to better manage pastures. There have been some notable successes. For example:

- correction of micronutrient deficiencies in Australian soils;
- the "sub and super" boom of the 1940's;
- analysis of flowering responses in plants leading to selection of pasture cultivars
- removal of the threat of phyto-oestrogens in subterranean clover by development of cultivars such as Trikkala and Leura, to replace the oestrogenic cultivars, Yarloop and Tallarook.

Although there has also been a long history of research into the physiological basis of grazing management, it is fair to say that until recently, the research has not had a major impact on the way that farmers manage the grazing of most pastures. Of course, there are exceptions: *e.g.* the essential need for rotational grazing of lucerne is well founded in an understanding of how lucerne must restore carbohydrate and protein reserves in its roots and crown after each grazing.

However, knowledge gained over many years of research is now proving valuable in formulating management tools for the future. We shall briefly outline some of the theory underlying pasture growth and utilisation, and how ideas have changed (improved ?) through time. For simplicity, we will only consider pastures grazed by sheep under variations of a set-stocked regime. Finally, we will discuss the physiological basis and use of GrassGro, a new decision support package for the grazing industries.

Use of sunlight by pastures

Plants intercept sunlight with their leaves and use the energy they capture to manufacture sugars from carbon dioxide in the air. The sugars are used primarily to drive plant growth, but are also stored in plant cells. The dilemma for a grazier is that one harvestable part of a pasture (leaf) is also the working part which generates new growth and pasture yield. A balance must be found between the amount harvested, or the frequency with which leaves are grazed, and the need to have leaves continually capturing sunlight to drive new growth.

The relationship between the leafiness of a pasture and its rate of growth is shown in Figure 1. Generally, as a pasture becomes more leafy it intercepts more sunlight and the growth rate of the pasture (kg DM/ha/day) increases. However, a point is reached when the pasture is sufficiently leafy to capture all light falling on it. At this point (known as the *critical leaf area index*), the pasture has the potential to grow at its maximum rate (*e.g.* review by Simpson and Culvenor 1987).

Following the early research that established this relationship, it seemed that pastures managed to maintain the critical amount of leafiness would grow at their maximum rate. Thus, if pastures were stocked at a grazing pressure which ensured that herbage was consumed at a rate equal to the maximum pasture growth rate then, in theory, animal production would also be maximised. However, two things make this an impossible management goal:

(1) pastures maintained near the critical leafiness begin to shade themselves and lower (shaded) leaves die at rates which increase with increased shading (Figure. 1);

(2) livestock eat preferentially the most digestible (youngest) leaves in the pasture, leaving the oldest and least photosynthetically-competent leaves.

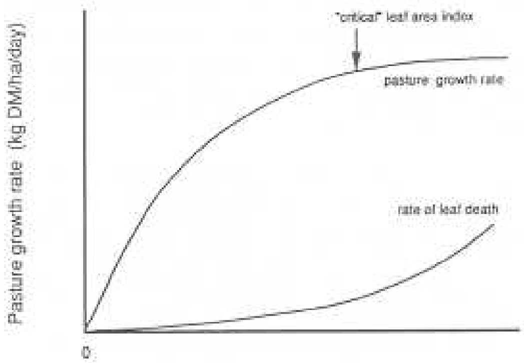

Figure 1. Generalised relation between the leafiness of a pasture (represented here by the amount of pasture on offer) and its rate of growth. Maximum growth rate is achieved when the pasture is sufficiently leafy to intercept all sunlight falling on it. This is said to occur at the "critical" leaf area index (critical leafiness). Note also that the rate at which leaves die in the pasture increases as the leafiness and, consequently, the internal shading increase.

The combination of these effects quickly results in tall rank pasture. The management of stocking pressure to match pasture intake with pasture growth rate is also difficult because of shifting seasonal growth patterns. However, as we will discuss shortly, such a scheme is presently used in Britain.

Pasture intake by grazing livestock

The undoing of these earliest attempts to establish a physiological basis for grazing management of pastures was that plant physiologists concentrated on maximising plant growth and ignored the needs of the grazing animal. It is also important to remember that the feed requirements of animals differ depending on their age (*e.g.* weaners *versus* mature), physiological condition (lactating *versus* dry) and the production aims of the grazing enterprise. For instance, for wool production from wethers it is important to maximise pasture intake per hectare; whereas for meat production, maximising intake per animal is much closer to the aim.

In the UK collaborating plant and animal physiologists have taken a different tack in understanding how to maximise pasture production (Parsons *et al.* 1983a; Parsons *et al.* 1983b). They established the relation between the amount of pasture consumed by sheep and the leafiness of the pasture (Figure 2). Maximum pasture intake by ewes with sucker lambs grazing perennial ryegrass swards occurred when the pasture was grazed to maintain the sward at a height of between 4-6 cm (typically this would be a pasture with about 1500 kg DM/ha). Pastures maintained at greater heights were undergrazed and much of the herbage was wasted as leaves died before they could be grazed. Pasture intake was lower on very short pastures because sheep found it physically impossible to eat enough grass. On very short pasture sheep spent more of the day foraging for grass and increased their "bite rate" (number of bites/day) to overcome the difficulty of obtaining feed from short pasture. However, the amount of pasture that could be taken in each bite was still inadequate.

The striking feature of these experiments was that pasture intake by sheep (and consequently animal production per animal, or per hectare) was highest when they grazed pasture that was not growing at its fastest rate (Figure 2). The availability of herbage in swards grazed to maintain a height of 4-6 cm was such that grass consumption by sheep was not physically restricted. The grazing pressure

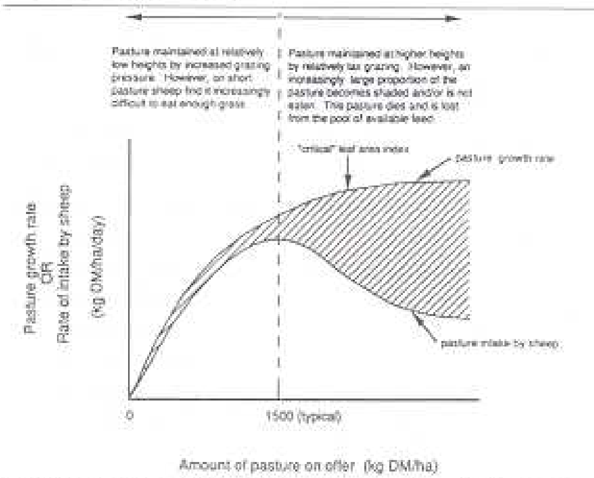

Figure 2. Generalised relation between the leafiness of a pasture, its rate of growth per hectare and the intake per hectare by sheep under continuous grazing. The relationship applies to pastures where the grazing pressure has been managed to maintain stable levels of pasture availability. Maximum intake by sheep occurs at a level of pasture availability below that necessary for maximum pasture growth rate to be achieved. Note the hatched area which indicates the amount of pasture lost to death and decay at each level of pasture availability.

and reduced internal shading of leaves ensured that pasture remained leafy with low proportions of stem, and with minimal pasture going to waste as senescing leaves.

Putting theory into practice

In Britain there are a number of recommended grazing systems in which sheep grazing is managed to accommodate the relation between grass intake and leafiness of pasture. One of these is shown in Figure 3. The aim is to maintain sward height as close as possible to 4-6 cm by spreading sheep over the whole farm and feeding supplements when pasture growth rates are low; or by concentrating sheep on a part of the farm and closing other areas for production of hay or silage when pasture growth rates are high (Anon.).

Do these management ideas apply to pastures in Australia?

Pastures in Britain differ from dryland pastures in Australia in a number of ways. The pastures for which the guidelines were devised are dense swards of perennial ryegrass, heavily fertilised with nitrogen, usually well-watered and are grown in a relatively predictable environment. Nevertheless, the general principles do apply to pastures in southern Australia. For instance at the extremes, sheep on very short pastures cannot maintain adequate feed intakes, and pasture is obviously wasted in understocked pastures. Pasture "bench marks" to guide livestock feeding are published by NSW Agriculture to address these issues.

The British grazing management guideline is, however, too simplistic for farming in our environment. In Australia, an analysis of grazing management strategies cannot be made without accounting for:

(1) seasonal extremes in pasture growth rates,

(2) shifts in the botanical composition of pastures, and

(3) the often wide year-to-year variations in rainfall patterns and amounts.

These features of our farming environment result in high levels of environmental risk, and consequently financial risk, which must also be managed

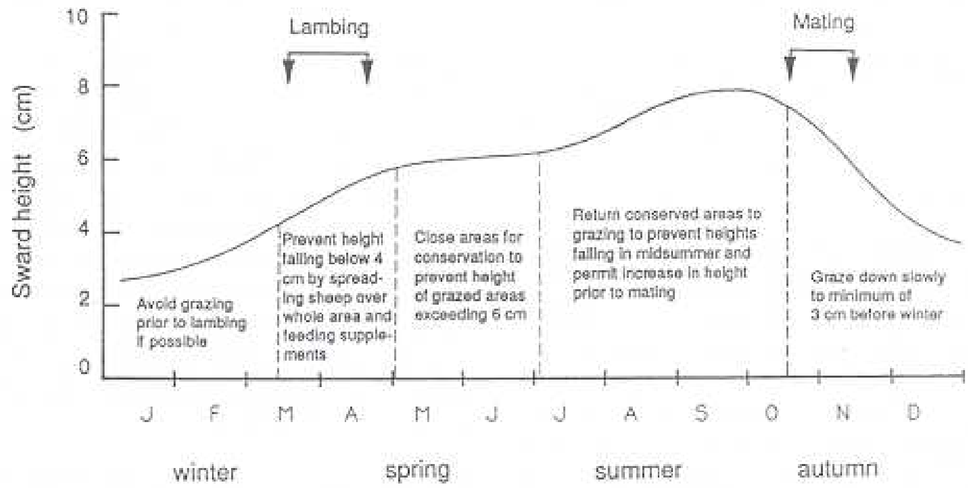

Figure 3. A management schedule for lowland sheep production in Britain as published by the Institute for Grassland and Animal Production at Hurley (via Maidenhead) (see Anon.). The scheme is based on management of sward height (leafiness) by varying grazing pressure through the year. The scheme was intended for fat lamb production.

as part of any grazing enterprise. In addition, in Australian farming systems, the cost of supplementing animals (for instance, to maintain an optimum pasture height) will often exceed the financial return from the "extra" pasture growth, and for some grazing enterprises (*e.g.* wool), it can be more efficient to "conserve" feed by allowing animals to store fat when feed is abundant and for the sheep to use the fat reserves as a source of energy when feed is scarce.

Recognition that analysis of the *whole grazing system* was required

Decision support systems for graziers

Some years ago it became obvious that knowledge of pasture physiology and agronomy alone was inadequate to manage a grazing system for profit. Complex interactions of weather, pasture growth and animal requirements must be considered and counter-balanced to allow the best management options to emerge. During the 1960's and '70's computer models of the many aspects of the biology in grazing systems were developed by scientists to explore the interactions between livestock production and pasture management. However, there was still a large conceptual leap to be made before computer models would add value to the information that advisers could give individual graziers.

Important and essential developments that have allowed the "conceptual leap" to occur are recent advances in computing technology and programming power. Today at CSIRO, we are developing computer-based decision support packages as part of our AUSFARM project. The packages allow details of your farm environment, soil types, management preferences, pasture types and animals to be entered into the computer as the basis of simulations of any alternative management option that you may wish to explore and analyse. The power of the computer-based package is that many options can be tested in a relatively short period of time as an aid to decision making in your farm business.

Decision support packages already developed under the AUSFARM project include: MetAccess, a weather analysis package (Donnelly *et al.* 1996); and GrazFeed, a package for management of livestock feeding at pasture (Freer *et al.* 1996). Both packages are available commercially[1] and are widely used. GrazFeed is also used in the PROGRAZE program of NSW Agriculture which is now entering its second phase and will be used across all southern states of Australia.

GrassGro - a decision support system for analysis of grazing enterprises

GrassGro is a new decision support system designed to analyse production options in the grazed pasture systems of southern Australia (see concept paper by Moore *et al.* 1991). GrassGro draws together the findings from years of research into pasture physiology and agronomy and combines them with knowledge of animal nutrition and production to simulate pasture growth and production from a mob of sheep or cattle grazing one or more paddocks under a specified management schedule (Figure 4).

To use GrassGro, the first input into the decision support system is a daily weather file for your farm or district. We now have the whole daily weather data base of the Australian Bureau of Meteorology stored on a single compact disk which simplifies this task. Sunlight, rainfall and temperature information are used to "grow" the pasture species that you select as representative of the species found in your pasture. Physiological information for each pasture species or cultivar is represented in the logic of the computer model in a way that is analogous to a "library card". The "card" describes how the pasture plant responds to environmental variables such as sunlight, temperature, moisture stress, *etc.*, and how it is stimulated to flower, set seed or become dormant *etc.* The botanical composition of the simulated pasture changes as the pasture species compete for light and water on the soil type that you have specified for the paddock.

Livestock are also represented in the model by "library cards" which describe the characteristics that control the nutrition and production of each animal species and breed. These characteristics are identical to the breed descriptions used in the GrazFeed decision support system for animal feeding. However, in GrassGro the livestock graze the simulated pasture under management rules that you have specified. Animals select the most digestible herbage first and try to eat enough each day to satisfy their appetite. If pasture is very short or of low quality, livestock may not be able to eat enough to survive and supplements are then fed under rules that you have nominated. Animal products (*e.g.* meat, wool *etc.*) are grown and are harvested as you specify. Annual gross margins for the grazing system are then calculated.

Footnote 1: MetAccess, GrazFeed and LambAlive were developed by CSIRO, but are marketed by Horizon Technology Pty Ltd, PO Box 598, Roseville, NSW, 2609. GrassGro is in the final stages of development at CSIRO.

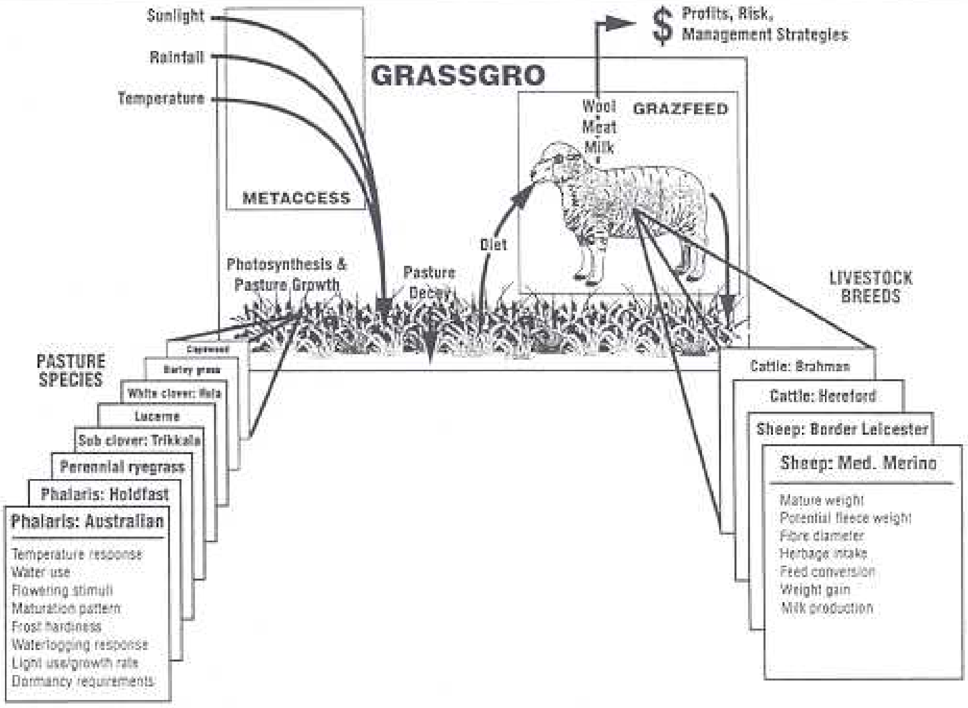

Figure 4. Schematic representation of the component models in the GrassGro decision support system for grazed pastures.

Analysing the risks and rewards of alternative grazing management options

An important feature of GrassGro is that pasture growth is responsive to daily weather information. The "pattern" of weather has a significant impact on how well pasture grows and "good" and "bad" pasture years are simulated as they occur in real life. A 20 year simulation of pasture growth on your farm (using historical weather information), therefore, reflects all of the optimism and heartbreak that you have experienced. The year to year fluctuations in weather and consequently production are revealed (Figure 5) and you can begin to analyse the "risks" associated with alternative pasture management options.

Analysis of "risk"

We use the year-to-year variability in gross margins as one way of measuring the risk involved in alternative management strategies. The variability of the gross margin is represented by its standard deviation (a statistical parameter) measured over all years in the simulation period. Larger standard deviations indicate wider variation in gross margin and greater financial risk. This is often associated largely with the weather received at each location but is also a product of the management rules (*e.g.* stocking rate, *etc.*) that are being tested.

An example of this sort of analysis is shown in Figure 6. Similar crossbred ewe/lamb grazing enterprises at Hamilton, Victoria and Cootamundra, NSW, are compared at various stocking rates. In this analysis, the enterprises differ only in the site

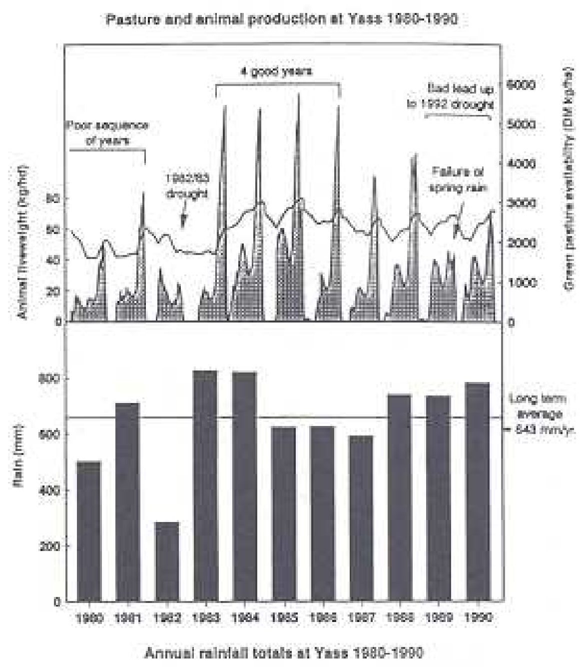

Figure 5. Rainfall, and simulations of green pasture availability and animal liveweight (——) at Yass, NSW for the period 1980 - 1990.

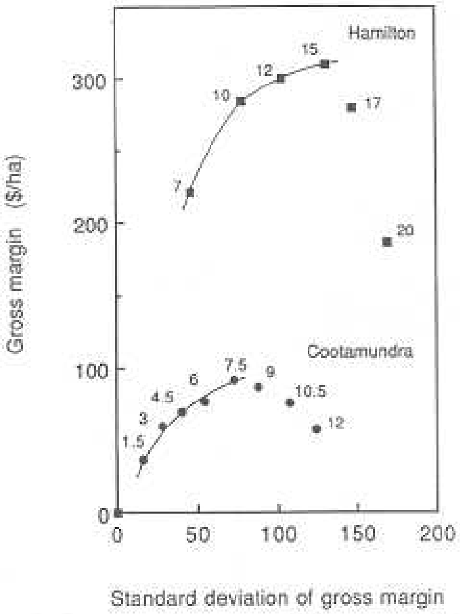

Figure 6. Gross margin and variability (standard deviation) of gross margin for crossbred ewe/lamb systems at Hamilton, Victoria and Cootamundra, NSW. Each gross margin value is the average of simulations based on weather records for Hamilton and Cootamundra from 1964 to 1982 and the standard deviation values reflect the variation in annual gross margins ov ' the whole period. The number associated with each point is the stocking rate (ewes/ha). The main assumptions of the simulations and gross margin calculation are: Animals were Border Leicester x Merino ewes mated to Border Leicester rams on 14 March each year; lambs were born 11 August, weaned 4 November and sold 29 December. Ewes only were shorn 30 December. Supplements were only fed to ewes if their fat score fell below 1.0. Animal husbandry costs were set at $2.50/hd/year. Pasture maintenance costs (mainly superphosphate) were $30/ha/year for pastures stocked at, or above 12 ewes/ha at Hamilton, or 6 ewes/ha at Cootamundra, but were reduced in proportion to the stocking rate at the lower stocking rates. (GrassGro fertility scalar set at 0.8). Wool and lamb prices were current for the date these simulations were first run: May 1996.

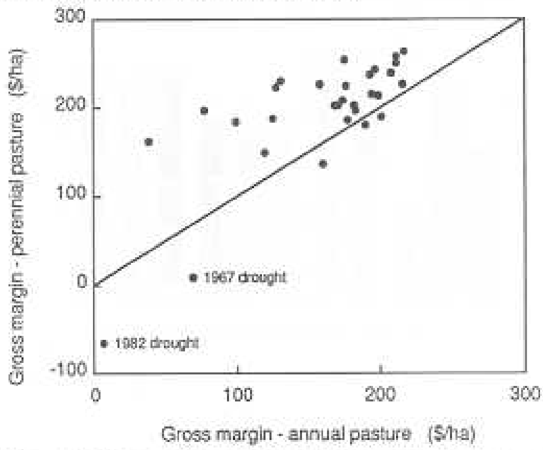

Figure 7. Comparison of annual gross margins for a crossbred ewe/lamb system based on perennial or annual pasture grown at Hamilton, Victoria (see Table 1). The diagonal line indicates where points would lie if gross margins for the two pasture systems were equal. Points above the line indicate a larger gross margin for the perennial pasture system.

weather patterns (historical data from each site are used; 1964 to 1992) and the pasture is presumed to be perennial ryegrass-subterranean clover at Hamilton and phalaris-subterranean clover at Cootamundra. The main bases for the gross margin calculation are outlined in the figure legend.

In this example, it appears that the ewe/lamb enterprise at Cootamundra returns considerably less per hectare and entails more financial risk. For example, standard deviation expressed as a percentage of the gross margin is always much higher at Cootamundra than at Hamilton. The main reasons for this are that the annual rainfall at Cootamundra is lower and, importantly, it is less reliably distributed through the year than at Hamilton.

The two sites are obviously not capable of sustaining similar stocking rates and the gross margin declines and the financial risk "blows out" (*i.e.* the point after which the standard deviation increases faster than the gross margin) at a lower stocking rate at Cootamundra. The analysis predicts that a reasonable stocking rate at Hamilton is probably about 12 ewes/ha and at Cootamundra, about 6 ewes/ha.

The analysis of many pasture management options will be more complex than the example above. For instance, in a second example we examine production from a ewe/lamb system based on either perennial pasture or annual pasture grown at Hamilton, Victoria (Table 1). In this situation the decision about which management option is the better is not clear cut and in the final analysis will also depend very much on the financial circumstance of the farm. In the example, GrassGro predicts that it is probably reasonable to operate at stocking rates up to 12 ewes/ha on both pasture types. If we accept that a stocking rate of 12 ewes/ha is reasonable, the perennial pasture returns a further $34/ha in gross margin. This is due on average, to a longer period of spring growth from the perennial pasture and heavier lambs for sale. Interestingly, the amount of supplements needed for feeding at around lambing is similar for both pasture types. However, the extra gross margin carries with it greater income variability. Figure 7 shows that the perennial pasture returns an equivalent or better gross margin than the annual pasture in most years, but there is predicted to be significantly poorer returns in two years that were severely drought-affected

Conclusions

Until relatively recently, the understanding of how plants function in grazed pastures has not contributed enormously to better grazing management. This has not been for want of trying, but was due to

Table 1. Predicted gross margins per hectare and their variabilities (risk) for a crossbred ewe-lamb enterprise based on annual grass-subterranean clover pasture or perennial ryegrass-subterranean clover pasture grown at Hamilton, Victoria.

Pasture type	moderately-fertilised, annual grass and sub clover pasture				moderately-fertilised, perennial ryegrass and sub clover pasture			
Stocking rate (ewes/ha)	**7**	10	12	15	**7**	**10**	12	**15**
Average liveweight of lambs when sold (kg/hd)	35.9	34.2	**33.8**	32.0	42.5	40.5	**38.4**	35.5
Average wool cut per ewe (kg/hd)	3.8	3.7	**3.7**	3.6	4.3	4.2	**4.1**	3.9
INCOME ($/ha)								
Animal sales: C.F.A.	17.43	23.92	**28.12**	33.33	18.24	25.50	**29.45**	34.26
lambs	167.68	231.08	**274.54**	327.94	193.01	265.85	**305.18**	356.93
Net wool sales	76.81	109.29	**131.35**	163.02	78.62	112.38	**134.56**	167.79
Total	261.92	364.29	434.01	524.29	289.87	403.73	469.19	558.98
EXPENSES ($/ha)								
Replacement stock	59.08	84.40	**101.28**	126.60	59.08	84.40	**101.28**	126.60
Replacement rams	16.33	23.33	**28.00**	35.00	16.33	23.33	**28.00**	35.00
Shearing costs	28.70	41.00	**49.20**	61.50	28.70	41.00	**49.20**	61.50
Other husbandry	11.20	16.00	**19.20**	24.00	11.20	16.00	**19.20**	24.00
Sale costs: C.F.A.	2.59	3.65	**4.34**	5.31	2.62	3.74	**4.43**	5.39
lambs	16.06	22.50	**26.85**	32.70	17.46	24.42	**28.54**	3 4.31
Pasture maintenance	25.00	5.00	**25.00**	25.00	25.00	25.00	**25.00**	25.00
Suppl ementary feed	3.35	12.31	**21.78**	49.70	3.65	11.90	**21.39**	58.00
Total	**162.32**	228.19	275.65	359.81	164.04	229.80	277.04	369.80
GROSS MARGIN ($/ha)	**99.60**	136.10	158.35	164.48	125.83	173.93	192.14	189.18
STANDARD DEVIATION OF GROSS MARGIN	20	38	53	92	29	56	75	104

Footnotes: Each value is the average of simulations based on weather records for Hamilton from 1964 to 1993. The main assumptions of the simulations and gross margin calculation are: Animals were Border Leicester x Merino ewes mated to Border Leicester rams on 15 March each year; lambs were born 12 August, weaned 4 November and sold 29 December. Ewes only were shorn 30 December. Supplements were only fed to ewes if their fat score fell below 1.0. Animal husbandry costs were set at $1.60/hd/year and pasture maintenance costs were $25/ha/year which included superphosphate applied at 75kg/ha/year (GrassGro fertility scalar set at 0.8). Wool and lamb prices were current for the date these simulations were first run: November 1995.

inadequate attention being paid to all aspects of the grazing system. Simply maximising pasture growth does not lead to maximum production because it ignores the needs of the grazing animal and the various production goals of a grazing enterprise. In addition, the difficult issue of risk management is not accommodated by any simplistic analysis of a grazing system.

Modern technology, in the form of the computer-based decision support system, now provides us with the tools to concurrently assess many features of grazing systems. GrassGro is such a decision support system. It draws on many aspects of our current understanding of pasture plant physiology, pasture agronomy and animal behaviour and nutrition to simulate the grazing system.

A few simple examples of typical GrassGro outputs were outlined here. They are only examples and it is quite likely that you may have questioned some of the assumptions used in each analysis. However, the real strength of GrassGro is that if you were analysing your own farming operations, you would modify the site specification and the management assumptions to suit your enterprise and your preferences. Your grazing enterprise could then be explored in terms of its potential productivity, financial return and the riskiness of that return. You can also examine how sensitive these are to management assumptions.

It should be obvious, that any predictions from a simulation should be accepted only after further consideration of their validity and suitability for your business operation. However, the simulations can provide unique and objective support for decisions about grazing enterprise management and may also assist planning for financial risk management and for coping with the production risks associated with the farm environments (*e.g.* drought).

We commenced this paper by claiming that it has taken a long time for plant physiology to contribute significantly to good management of grazing systems. It is, therefore, ironic that we are now finding that the largest impediment to our efforts to rapidly improve GrassGro and other AUSFARM decision support systems is our rather poor and fragmented basic knowledge of the soil, plant and microfauna environments of our farming systems.

Acknowledgments

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