Temperate Pastures for Grazing Livestock

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ABSTRACT: This series of papers reviews the literature and reflects on those characteristics of temperate pastures and their management that influence grazing value and sustainability. In temperate environments, pastures provide the primary feed resource for extensively managed livestock. Evidence for the superiority of improved legume-based pastures compared with indigenous pastures is well established; pasture management guidelines that achieve profitable and sustainable livestock systems are well developed; and plant breeding is developing new pasture varieties with genetic improvement in attributes that confer enhancements to seasonal yield, nutritive value and product quality. However, previous pasture research has been undertaken in the context of in situ input-output relationships, and it is proposed that future research needs to broaden its scope to account for impacts on the soil, plant and livestock resources in the wider pastoral landscape.

Key Words: Improved Pastures, Grazing Value, Sustainable Pastures, Plant Breeding

INTRODUCTION

For the grazing industries in temperate environments in Australasia, there have been 2 discrete eras of significant change; an era of pastoral expansion in the 19th century facilitated by innovations in mechanisation and transportation, and an era of pastoral intensification from the mid-20th century fostered by expanding export markets and new technologies that improved livestock health, nutrition and breeding. Transition to a third era, that of pastoral rationalisation determined by adverse terms of trade, a declining resource base, and a public agenda of environmentalism appears to be underway.

The following papers highlight evidence for the contribution of improved pastures to grazing production (Ayres et al. ibid), and describe the potential of new pasture cultivars to improve animal production and product quality (Caradus et al. ibid). A third paper (Scott et al. ibid) examines the key elements of sustainability – a critical issue of relevance to pasture research in this emerging era of pastoral rationalisation.

THE CONTRIBUTION OF PASTURE RESEARCH FOR ANIMAL PRODUCTION FROM LEGUME-BASED PASTURES IN TEMPERATE AUSTRALIA

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ABSTRACT: The major factor in the innovation of pasture technology in Australia has been the contribution of pasture improvement, namely the dual practice of sowing adapted legumes and fertilising with superphosphate. Pasture improvement based on white clover and superphosphate has been very successful, but by the 1980’s poor persistence of imported cultivars emerged as a major problem; a local program of white clover improvement has been underway since 1987. For subclover-based pastures, there is a 40 million ha gap between the area currently planted and the potential area; research to determine whether this gap is due to technical or economic constraints is of high priority. Future pasture research will be supported by advances in economic analysis and environmental statistical modelling. As sustainability and resource use issues become more prominent in the public debate, new practices will be evaluated by economic analysis that considers consequences for stocks of pasture, soil, and livestock resources in addition to traditional input - output considerations. Statistical modelling has the power to exploit non-treatment variability for more efficient design and greater precision of analysis, and allows utilisation of large and complex data-sets for predictive purposes.

Key words: Pasture Improvement, Introduced Species, Native Pasture, White Clover, Subclover

“Pasture legumes and superphosphate are the basis of improved agriculture in southern Australia … nothing exists in present or foreseeable technology to indicate this will change in the next hundred years” (Gladstones 1975).

The introduction of pasture legumes to Australia

Subclover (Trifolium subterraneum L.) is the most prominent of a large number of annual herbage derived from accidental introductions to Australia from the Mediterranean basin. Credit for recognition of the potential of subclover for Australian pastures goes to the nurseryman Amos Howard who from 1890 collected and distributed seed and publicised subclover
to farmers and State Departments of Agriculture (Spafford 1924). When fertilised with the macro-nutrients P, Ca and S (and where necessary the trace elements Cu, Zn and Mo), subclover revolutionised Australian agriculture from the 1930's. The discovery of the significance of Mo for the growth of subclover (Anderson 1942) is one of Australia's major contributions to international agriculture.

White clover (Trifolium repens L.) is indigenous to Europe and was first introduced to the USA, Canada, NZ and Australia with European settlers. In Australia, white clover disseminated through the high rainfall zone by i) accidental introductions with settlement in the late 18th century, naturalising in conjunction with pastoral expansion through the 19th century, and planting of imported cultivars in the 20th century. By the 1930's, Departments of Agriculture were recommending pasture improvement based on white clover and companion grasses such as phalaris (Phalaris aquatica), cocksfoot (Dactylis glomerata) and perennial ryegrass (Lolium perenne) fertilised with superphosphate (Donald 1970). With the advent of mechanisation and aerial spreading of seed and fertiliser, high wool prices, favourable seasons and a reduced feral rabbit population, white clover and improved pasture technology were popularised and a "pasture revolution" occurred resulting in rapid expansion of pasture improvement through the 1950's and 1960's.

Zones of adaptation

In southern Australia, the subclover and white clover zones are approximately adjacent. Subclover has become widely naturalised across the south of the continent, the zone of adaptation totals 29.3 m ha with potential to expand to 71 m ha (Australian Temperate Pastures Database). Three climatic factors determine the boundaries; an arid limit - where rainfall is so low that there is insufficient moisture in spring for flowering and seed set, a heat limit - a northern limit beyond which cold requirements for flowering are not met, and a cold limit - determined by elevation above which seed production is adversely affected (Donald 1970). The white clover zone extends over 7.8 m ha with potential to extend to 16 m ha; the zone of adaptation corresponds to the temperate perennial pasture zone where AAR exceeds 700 mm, length of the growing season is protracted, and summers are mild and moist. White clover is sown in conjunction with phalaris, tall fescue, cocksfoot and perennial ryegrass as permanent pasture and has ingressed substantially into native pastures.

The advantages of introduced pasture species

Native vegetation provides a poor feeding regime for grazing animals. Tree and shrub communities offer little nutritious feed and limit the growth of under-canopy forage species. Native species may ipso facto be well adapted to local conditions but are deficient in characteristics important for grazing value. Typically, native grasses have a short growing season and present high quality green pasture biomass for only a limited period of the year. Most warm-season native grasses have low levels of green leaf in deference to fibrous stem, and through low frost tolerance present senesced residues of poor nutritive value in winter. By contrast, the advantages of introduced species are that they possess greater yield potential, higher nutritive value, and a capacity to extend the growing season and retain green leaf through winter.

The merits of improved legume-based pastures rest on the following foundations; i) where soil mineral status is adequate, the legume contributes to soil fertility (particularly soil N through the N accretion process), ii) increase in soil N supports the adaptation and performance of high yielding introduced grasses and promotes the ingress of more vigorous and desirable native grasses, and iii) a legume/grass sward provides a diet conferred with the inherently higher nutritive value of legumes - enriched protein and mineral status, reduced structural fibre, increased digestibility, rapid rate of passage and stimulus to intake.

Subclover in winter-rainfall environments

Fertilised subclover-based pastures produce 3 - 6 fold greater green biomass per hectare than unfertilised native pasture. For example, Davies et al. (1934) reported cumulative pasture availability of 8570 kg DM/ha for subclover-based pasture at Kybybolite, South Australia compared with 1060 kg DM/ha for native pasture; Lloyd Davies (1963) reported 7400 kg DM/ha spring growth for subclover/phalaris pasture at Canberra compared with 1500 kg DM/ha for native pasture.

In addition to increased level of pasture production, the feeding value of subclover is high. Some representative data for feeding value are; in vivo digestibility of 0.69 - 0.77 for spring forage (Freer and Jones 1984, Ridley et al. 1986, Mulholland et al. 1996), 54 - 96 kg wool/ha for wether sheep from grazing studies in South Australia, Western Australia and Victoria (Carter and Day 1970, Lloyd Davies and Humphries 1965, Drake and Elliott 1965), and 281 - 400 kg weight gain/ha for steers from grazing studies in Victoria (Hamilton and Bath 1970, Vivian 1969).

An important feature of the nutritive value of subclover is that mature residues retain sufficient quality to minimise weight loss through the summer dry-season compared with companion grasses (Ridley et al. 1986). The work of Mulholland et al. (1996) indicates potential to increase the nutritive value of subclover through a) use of late maturing varieties, and b) breeding for increase in petiole fraction which is high in digestibility compared with leaf and stem, and is the major contributor to pasture biomass. An animal health problem associated with subclover is reduced fertility in sheep due to phytoestrogens. However, the discovery of varietal differences in estrogenicity and the association of estrogenic activity with
fromononetin concentration (Lloyd Davies and Bennett 1962) led to the release of low fromononetin varieties to reduce the severity of fertility problems.

White clover in summer-rainfall environments

Before the advent of pasture improvement, pastures on the Northern Tablelands of New South Wales supported only 2 sheep per hectare and breeding replacement stock to maintain flock size was infeasible because of flock mortality rates of ca. 25% per annum (Eastoe and Tindale 1963). Roe et al. (1959) were the first to study these limitations on native pastures for sheep production in temperate Australia; they reported that green pasture biomass of grazed native pasture was in the range 100 - 1100 kg DM/ha year-round, produced little green leaf in winter, and sheep production was limited by low forage protein. Research in the 1950's and 1960's identified the value of improved pastures based on white clover to be the most effective and profitable means of increasing animal production (Robinson 1968). Cotsell and Edgar (1957) found that providing sheep with partial access (3.5 days/week) to white clover-based pastures increased carrying capacity from 1.8 to 5 sheep/ha, wool production from 7.9 to 18.7 kg/ha and flock replacement from 25% annual mortality to a 5-fold increase in flock size within 6 years. Cotsell and Edgar (1959) found that providing sheep with full-time access (compared with partial access) to white clover-based pastures promoted further increases in sheep production; carrying capacity increased to >10 sheep/ha, reproductive rate increased from 73% to 81%, wool production increased by 21.3% per animal, and mortality rate declined from 5.17% to 1.37% per annum.

Accordingly, sheep breeding was projected from being infeasible on native pastures to being both feasible and profitable on white clover-based pastures. A series of trials and demonstrations followed over the next 20 years confirming that white clover-based pastures support a stocking rate of 10-12 sheep/ha, producing ca. 4 kg wool/sheep with annual mortality of 2% per annum (Eastoe and Tindale 1964, Tindale et al. 1966, Simpson and Robinson 1968, Cotsell 1969). Contemporary research (McPhee et al. 1997, Ayres et al. 2000) showed that grazed white clover-based pastures present green pasture biomass in the range 750-2500 kg DM/ha year-round supporting 10-15 wethers/ha and producing high levels of wool production (ca. 60 kg wool/ha) of commercially acceptable quality (18 μm fibre diameter, >50 N/k tex staple strength).

New directions

Environmental statistics - Future pasture research will be undertaken in the context of the need to know the full impact of agronomic practices on key environmental resources as well as direct effects on pasture and animal production. Statistical models will encapsulate global considerations (economic, environmental) as well as elucidation of cause and effect at the local level; datasets will be large, complex and unstructured.

The classical aim of pasture research has been to distinguish systematic variability (treatment, time) from variability due to random sampling of plots and sites. Conventionally, random effects have been viewed as nuisance effects and the main focus has been on estimating the systematic effects. Modern modelling methods (Gilmour et al. 1997) attach importance to both types of variability so that the model is more general and results can be extrapolated more readily to new situations. A feature of statistical modelling is that it allows adjustment of data to correct for spatial variation to improve the efficiency of experimental design and the power of the analysis.

Developmental work with statistical modelling has been successful with field crops. Adaptation of this methodology to pastures is more problematical because of the extra inherent variability. For example, in plant improvement work, a pasture cultivar comprises a population of genotypes occupying a diversity of micro-sites and both shoot and root systems are defoliated in ad hoc fashion by a host of predators. The extra variability in pasture data clouds parts of the model. Nevertheless, the same strategies of identifying random effects and modelling large scale effects, followed by effects of smaller magnitude, provides a more precise understanding of cause and effect.

Remote-sensing is another new development with implications for environmental statistics that offers a strategy for large scale sampling at low cost (Hill et al. 1999). Making biological sense of satellite images requires mathematical and computing expertise in conjunction with calibration of image characteristics against landscape measurements.

Economic evaluation - Conventionally, the significance of new pasture technology has been considered as an input-output process and evaluated by a variety of economic tools depending on the context; physical/financial budgets, cash flow analysis, discounting procedures to calculate economic parameters, simulation and econometric models. However, as resource use and sustainability issues have become more prominent in the public debate, focus has shifted to consideration of managing stocks of resources (eg. pasture, soil fertility, livestock) over time. In this framework, on a farm or in a region, the stocks are controlled by decisions on pasture management, animal husbandry and resource use. The outcomes from management decisions include products for sale plus changes in stock levels. These outcome responses are dynamic in nature because future stock levels depend on the interaction of current management decisions and current levels of stocks with interim climatic events. In the context of sustainability, the dynamic temporal nature of the pastoral system is more important than recognised by conventional economic analysis (Wang and Hacker 1997).
Dynamic optimisation methods can be adapted to address the resource use issues; these include optimal control theory and dynamic programming (Kamien and Schwartz 1991). An example of the use of this approach is in the Sustainable Grazing Systems Key Program in southern Australia (Mason and Andrew 1998). In this major national project, land degradation outcomes from agricultural activities are being assessed using a bio-economic framework in a sustainable resource management context. The economic component of the project involves linking a simulation model of pasture/soil/water processes with dynamic programming analysis of management options. The results are presented in the form of optimal resource-use pathways. Dynamic programming reports both the optimal state (eg soil pH) over time, the decisions used to manoeuvre along the land-use pathway (pasture strategy, fertiliser rate etc), the income derived from the pathway, and any other physical variables of interest from the simulation model. It is possible to assess pathways for different environments, commodity prices and scientific assumptions.

Where this optimising framework based on neoclassical economic theory is used in the context of sustainable resource use, there will be greater emphasis on systems research - increased understanding of the economic and biophysical characteristics of sustainability will be achieved.

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IMPROVED GRAZING VALUE OF PASTURE CULTIVARS FOR TEMPERATE ENVIRONMENTS

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ABSTRACT: Grazing value of temperate pastures is determined through the impact of feed intake on animal product quantity and quality. Plant factors that are considered important determinants of product quantity and quality include productivity, seasonal growth, protein/energy balance, by-pass protein level, leaf properties affecting intake, resistance to foliar diseases, and compounds that affect animal health and welfare, reproductive fertility, and product flavour and texture. Plant improvement programs have achieved genetic gains in excess of 1% per year for yield and nitrogen fixation. Significant heritable variation exists for soluble carbohydrate and fibre fractions in grasses, and in the rate at which these change during the season. Biotechnology also provides the opportunity to increase soluble carbohydrate levels allowing effective utilisation of protein in feed. The incorporation of condensed tannin-containing plants in the diet will improve by-pass protein levels. Deleterious animal health and welfare effects can be alleviated through the use of non-toxic endophytes in grasses, and some forages that exhibit anthelmintic-like affects. The introduction of novel feeds can provide high yielding, pest and disease resistant, and persistent forages. While these continue to be important, breeding objectives have diversified to include improved protein/energy balance, increased by-pass protein levels, leaf properties affecting intake, and manipulation of compounds that affect animal health, animal welfare, reproductive fertility, animal product flavour and texture.

Grazing value equates substantially to feeding value defined as an animal production response and quantified by weight gain or milk yield. Nutritive value is a response per unit of feed intake. Thus, feeding value is a function of both intake and nutritive value (Ulyatt 1973). Grazing value in this paper is an extension of feeding value to include the impact of forage on animal health and welfare, and quality of the final animal product produced.

Yield

Genetic gains for annual and seasonal yields have been achieved across a range of temperate forage grass and legume species (Woodfield 1999). In New Zealand, over the past 60 years, the genetic improvement for yield of perennial ryegrass, annual ryegrass, and tall fescue, has been between 0.25 and 1.18% annually. These improvement rates compare favourably with European reports of 0.5% per year for perennial ryegrass and annual ryegrass (van Wijk & Reheul 1991).

Genetic gains for yield have generally been higher for white clover (1.2 to 4% annually) and red clover (0.21 to 1.39% annually) than for lucerne (0.35% annually) (Woodfield 1999). In New Zealand, the rate of genetic gain for white clover yield has accelerated over the past decade. Prior to 1985, genetic improvement increased at a rate of between 0.4 and 0.6% per year under sheep and cattle grazing, while the rates since 1985 have exceeded 2.5% annually (Woodfield 1999).

In most temperate regions, and particularly in Australia and New Zealand, grazed pastures provide the major source of feed for animal production. Although pastures have variable nutritive value in comparison with concentrate feeds, they remain the preferred nutritive source because of their low-cost and their competitive advantage in terms of world trade of agricultural products. Legumes are incorporated into pastures to improve nutritive value and intake rates. More recently, herbs such as chicory have been introduced for similar reasons.

Plant breeding programs traditionally focussed on providing high yielding, pest and disease resistant, and persistent forages. While these continue to be important, breeding objectives have diversified to include improved protein/energy balance, increased by-pass protein levels, leaf properties affecting intake, and manipulation of compounds that affect animal health, animal welfare, reproductive fertility, animal product flavour and texture.

Figure 1. Lamb liveweight gains when grazed on six perennial ryegrass cultivars in 1997 and 1998 (adapted from Westwood & Norriss, 1999).
These increases in yield are also reflected in increased grazing value (Woodfield 1999). Estimated genetic gain for grazing value ranged from 0.3 to 1.37%, with the highest rate reported for liveweight gain of lambs grazing recent perennial ryegrass cultivars in comparison with Grasslands Nui (Fig. 1).

Persistence
Persistence in forages is particularly complex since a deficiency in any one of a range of traits can result in poor persistence. It can also be inversely correlated with yield. The ability of a plant to persist is influenced by grazing and management, pests and diseases, nutrient deficiencies or toxicities, climatic factors, interplant competition and genetics (Woodfield & Cardus 1996). Persistence is also genetically complex due to the many plant characters and environmental factors that interact, and breeding is made more difficult by variable requirement for expression of each trait between locations, seasons and years. Plant characters that are critical for persistence in one environment (e.g. disease resistance) may not be involved in another environment (e.g. nutrient deficiency). Conversely, presence of non-lethal levels for one stress (e.g. moisture stress) may result in poor persistence when a second stress (e.g. pest attack) occurs.

Table 1. Heritability of white clover characters linked to persistence in stress environments (Cardus et al. 1990, 1991; Cardus & Chapman 1996; van den Bosch et al. 1997; van den Bosch & Mercer 1997; Woodfield & Cardus 1990).

<table>
<thead>
<tr>
<th>Plant character linked with persistence</th>
<th>Narrow-sense heritability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Winterhardiness</strong></td>
<td></td>
</tr>
<tr>
<td>Frost tolerance</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>Grazing pressure</strong></td>
<td></td>
</tr>
<tr>
<td>Leaf size</td>
<td>0.52</td>
</tr>
<tr>
<td>Stolon branching</td>
<td>0.37</td>
</tr>
<tr>
<td>Stolon elongation rate</td>
<td>0.25</td>
</tr>
<tr>
<td>Node appearance rate</td>
<td>0.38</td>
</tr>
<tr>
<td>Internode length</td>
<td>0.36</td>
</tr>
<tr>
<td>Stolon diameter</td>
<td>0.66</td>
</tr>
<tr>
<td><strong>Drought</strong></td>
<td></td>
</tr>
<tr>
<td>Taproot diameter</td>
<td>0.54</td>
</tr>
<tr>
<td>Number of large nodal roots</td>
<td>0.08</td>
</tr>
<tr>
<td>Root:shoot DM ratio</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Soil-borne pests</strong></td>
<td></td>
</tr>
<tr>
<td>Clover-cyst nematode resistance</td>
<td>0.43-0.61</td>
</tr>
<tr>
<td>Root-knot nematode resistance</td>
<td>0.17-0.40</td>
</tr>
<tr>
<td><strong>Low pH, low P soils</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminium tolerance</td>
<td>0.53</td>
</tr>
</tbody>
</table>

¹ Broad-sense heritability estimates

The length of time required to adequately assess persistence slows genetic progress. Identification of specific plant characters affecting persistence would be advantageous. The heritability of some characters associated with improved white clover persistence in a range of stress environments indicates that response to selection for these traits should be achievable (Table 1). Selection responses for nematode resistance have reflected their relative heritability estimates (Table 1). Resistance to clover cyst nematode has exceeded 7.3% per cycle, while the response for resistance to root-knot nematode was 2.3% per cycle (Mercer unpubl. data). Similarly, selection for increased taproot diameter, which had a narrow-sense heritability of 0.54, resulted in a gain of 2.4% per cycle over 3 cycles of selection (Woodfield et al. 1996).

Energy and protein balance
Pasture plants are frequently rich in protein and relatively poor in non-structural carbohydrates. As a result, much of the protein ingested is metabolised for energy by rumen micro-organisms, and losses of up to 40% of dietary nitrogen have been recorded (Ulyatt et al. 1988). Protein losses can be prevented by feeding animals carbohydrate supplements. Conventional selection for high soluble carbohydrate levels was successful in a perennial ryegrass across a range of environments (Smith et al. 1998). The selected lines also tended to have higher herbage protein content and higher digestibility, but soluble carbohydrate content was increased relative to controls by more than these. Soluble carbohydrate levels were reduced (by 67% in one instance) by rust infection. The introduction of genes from other plant species that have high soluble carbohydrate levels is an option. Under appropriate conditions, genes for novel storage carbohydrates can accumulate to significant levels in plant tissues without being broken down.

By-pass protein
Condensed tannin present in pasture legumes such as birdsfoot trefoil, Greater lotus, sulla and sainfoin has provided increased liveweight gain, wool growth and milk production from both sheep and dairy cows, and improved milk composition (Waghorn et al. 1998). Not all condensed tannins provide animal production benefits and excessive levels of condensed tannin can be detrimental. Unfortunately the major legumes (e.g. white clover, lucerne and red clover) that are adapted to grazing do not contain condensed tannin in their leaves. Furthermore, the tannin-containing legumes are poorly adapted to grazing, however, selection to improve the persistence under grazing of birdsfoot trefoil, Greater lotus, sulla and sainfoin is underway (Waghorn et al. 1998). This approach should be successful since these legumes have undergone minimal selection to this point and have considerable genetic variation for adaptive traits.

Intake rate
Legumes, and particularly white clover, are included in temperate pastures because they improve feeding value. White clover improves feeding value for young sheep by 50-100% over grasses and by 15-
35% over other forage legume species (Ulyatt 1981). This results from greater intake, rapid particle breakdown, digestion, absorption and metabolisable energy content of white clover. Few attempts have been made to increase the intake rate of grasses by selection and breeding. Decreased leaf toughness, leading to increased rate of particle breakdown, has been achieved by selection for lower leaf shear strength in perennial ryegrass (Easton 1989). In spring, herbage intake by sheep was higher when grazing low leaf shear strength ryegrass, and the rate of dry matter disappearance in cattle rumen was faster, but the results were inconsistent (Inoue et al. 1994).

Intake rates of grazed pastures are lowered by increased incidence of fungal leaf diseases, an example of this is the severely reduced intake associated with rust infection (Table 2).

<table>
<thead>
<tr>
<th>Rust class</th>
<th>No. of plants</th>
<th>Herbage eaten (% of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – Rust free</td>
<td>26</td>
<td>99</td>
</tr>
<tr>
<td>1</td>
<td>109</td>
<td>83</td>
</tr>
<tr>
<td>2</td>
<td>174</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>247</td>
<td>18</td>
</tr>
<tr>
<td>4 – Severe rust</td>
<td>119</td>
<td>1</td>
</tr>
</tbody>
</table>

**Animal health and welfare**

A number of attributes of pasture species can impact on animal health and welfare. For example, fungal endophytes in grasses can cause ryegrass stagner, fescue toxicosis, and heat stress in animals. High clover intake may result in bloat, fungal diseases on legumes can increase the levels of oestrogenic compounds causing increased infertility, fungal saprophytes can produce zearealnone (another oestrogenic compound) or a toxin causing facial eczema, and low leaf magnesium levels can cause hypomagnesemia. Additionally, some forages have inherently high phyto-oestrogen levels and yet others exhibit anthelmintic-like effects reducing the severity of internal parasite burdens.

The endophytes typically associated with perennial ryegrass and tall fescue produce a range of alkaloidal metabolites. The most important of these are lolitrem B, which is the main toxin that induces ryegrass stagner, and ergovaline, which is the principal toxin involved in fescue toxicosis. These same wild-type endophytes do have beneficial properties such as resistance to various insect pests and increased persistence of endophyte-infected plants (Easton 1999). For example, peramine produced by endophytes deters Argentine stem weevil feeding. Endophyte-free grasses overcome the animal health problems identified but frequently lack persistence due to the absence of the beneficial insect resistances. Identification of non-toxic endophytes that do not produce lolitrem B and ergovaline, but which continue to provide the alkaloids responsible for the necessary insect resistance is being pursued (Fletcher 1999).

Internal parasites reduce animal performance and are expensive to control. Condensed tannins extracted from pasture legumes have been shown to reduce the development of eggs to L3-larvae of the sheep nematode in *in vitro* assays (Molan et al. 1999). The proportion of eggs which hatch was also reduced by condensed tannins. Condensed tannins in birdsfoot trefoil have also provided higher ovulation rates in sheep (Waghorn et al. 1998).

The concentrations of macro- and micro-nutrients in forages directly affect animal health and performance. Inadequate levels of Mg and Ca in perennial ryegrass are associated with ryegrass stagner and milk fever, respectively, while low levels of Na reduce stock performance and may increase susceptibility to bloat. Easton et al. (1997) reported significant genetic variation in perennial ryegrass for concentrations of 8 nutrients, with narrow-sense heritability estimates ranging from 0 to 0.9. Efforts to optimise the levels of these nutrients are underway.

Selection for enhanced herbage Mg in Italian ryegrass produced significant difference between lines, and this was reflected in serum Mg of grazing lactating ewes and the incidence of hypo-magnesemia (Moseley & Baker 1991).

**Product flavour and texture**

While pasture-based animal production systems are inexpensive, they result in meat and fat colour, fat composition, and odour/flavour that are noticeably different from grain-fed animals (Young et al. 2000). Grain diets also promote the accumulation of muscle glycogen resulting in a lower final pH meat than grass/clover fed animals.

In New Zealand and Australia, lower energy pastoral diets result in unmarbled beef. While this may be desirable from a health viewpoint, marbled beef produced on grain fed diets receives a market premium in most markets. This may be the result of both diet and pre-slaughter stress. Stress induced by mixing herds and transport prior to slaughter depletes glycogen.

The odour/flavour of meat from animals fed grass/clover diets are often described as unpleasant (‘fishy’, ‘rancid’ or ‘barnyard’) in overseas markets. Several studies have correlated fatty acid profile with pastoral odour. Causal relationships between oleic acid content (of feed) and desirable flavours and between linolenic acid content and undesirable flavours have been proposed (Young et al. 2000). Additionally, some pastoral flavour compounds such as skatole (Lane & Fraser 1999) can be related to the higher protein and much greater ratio of protein to readily digestible carbohydrate in pasture diets. Increasing the ratio of carbohydrate to protein in pasture diets may reduce this problem, but changing their fatty acid profiles may be much more challenging.
The incentive to produce white fat is market-driven since some overseas consumers equate yellow fat with disease. β-carotene is the major contributor to yellow fat, and its levels can be 100 times higher in fresh pasture than in grains. Antioxidant status of pasture-finished meat is important in slowing oxidative browning of exported meat products that may be stored for many weeks before appearing on supermarket shelves. Antioxidant concentration varies with pasture age and season, and is probably reflected in colour stability of stored meat prior to sale.

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MANAGING PASTURES TO ACHIEVE SUSTAINABLE GRAZING ENTERPRISES

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ABSTRACT: Sustainable grazing enterprises are described as those supported by a number of productive layers, including economic profit and more fundamental layers of animal, plant and soil resources. Several myths popularly associated with sustainability are challenged. These include biodiversity, the level of inputs, the role of fertilizers, and claims made for prescriptive grazing systems. The principles of profitable livestock production are highlighted including the need for adequate digestible green leaf, productive species, adequate fertilizer inputs and sound management to ensure persistence of desirable plants, especially through stresses such as drought. A generic response surface between stocking and fertilizer rates and wool production is presented, suggesting an optimum range between levels of inputs (fertilizer) and stocking rate with raw wool production.

Key Words: Stocking Rate, Fertilizer, Biodiversity, Species, Persistence

INTRODUCTION

In the higher rainfall areas of Australia, managing pastures to sustain the profitability of grazing enterprises over the long-term is a challenging task requiring the balancing of adequate, appropriate and cost-effective inputs with the production of marketable outputs derived from these enterprises. A ‘sustainable’ grazing enterprise requires a profitable level of livestock production to be achieved and maintained without detriment to the plant and soil resources which support production. Whilst such production can at times be achieved using pasture species native to Australia, it is usually only when the pasture is modified through the addition of fertilizer and introduced species, including grasses and especially legumes, that sufficient quality of pasture is attained to support profitable livestock production. Thus, this paper will focus mainly on the management of introduced pasture species in the higher rainfall areas of Australia.

Sustainability

Attempts to define ‘sustainability’ have been made by numerous authors. Reeve (1990), for example, states that the concept includes the on-going production of food and fibre for a stable human population in such a way that use of non-renewable resources is minimised, whilst being profitable for farmers and yet without negative off-site impacts. Of course, it must be remembered that it remains a social construct (Lambert et al. 1996) and hence is open to a wide range of interpretations. Following our research efforts which aimed to quantify the ‘sustainability’ of three grazed pastures (Scott et al. 2000), we conclude that measures of ‘sustainability’ should include both biophysical and economic components, trends over time of the status of the resources on which the system depends, and assessments of off-site effects.

Time trends

The definition of sustainability usually includes reference to time or inter-generational changes. Ideally, long timeframes - of at least decades - should be considered when discussing sustainability. Broadly based survey data obtained periodically (e.g. a number of pasture surveys cited in Wilson and Simpson 1993) can suggest historic trends but are poor at identifying cause and effect. However, data from individual experiments are often limited in providing trend lines assessed over short periods of several years or less (e.g. Scott et al. 2000).

Important ‘layers’ of sustainability

Scott et al. (2000) presented a conceptual diagram depicting a hierarchy of sustainability layers indicating that a farmer’s financial returns depends on the more fundamental layers of resources of animals, plants and soil. We know that farmers in Australia tend to focus more on livestock health, marketable products and economic returns than on either the vigour of their pastures or the health of their soils (MacLeod and Taylor 1992; Lees and Reeve 1994). In stark contrast, the biophysical importance of soil retention and quality is, over the long-term, greater than that of pastures, which in turn are of greater import than animals. Only those farmers who remain profitable over the long-term, in spite of declining terms of trade, are likely to be able to afford to maintain the inputs needed to sustain their natural resources in all three components (animals, pastures and soil) over time.

In circumstances where low financial returns mean that farmers cannot afford to care for their soil resources, or where land is not owned by the farmer (e.g. on communal grazing lands in many developing countries or in the USA where government grazing rights encourage overgrazing - Holechek and Hess 1995), it is usually society at large which ultimately bears the burden of paying for degradation that may occur. Thus, it is of great importance to the prevention of land degradation that land tenure systems encourage sound land stewardship, and that farmers manage their resources profitably to achieve both economic and ecological sustainability over the long-term.

Factors affecting sustainability

Rainfall amount, variability and seasonality - The ability to regularly harvest products with desirable market characteristics is a challenge to most grazing enterprises, especially in Australia with its highly variable climate. Surviving adverse seasons with soils and pastures in good condition is crucial to
sustainability, so that when favourable conditions return, animal production can resume undiminished.

**Plant species** - Pasture plant persistence is affected not only by climatic and soil factors but also by inter-species competition, by nutrient supply and by management. Species range widely in their digestibility and persistence and these attributes affect the importance of grazing management to plant survival. In a study of 6 perennial grasses defoliated under drought, Boschma and Scott (2000) found that species differed markedly in their tolerance to drought (from 0 to 40% mortality in one season).

They also differed greatly in production of green digestible leaf with predicted sheep liveweight gains from the 6 different grasses under drought varying from 20 to 110 g/day. Moderate defoliation of plants subjected to drought resulted in higher soluble carbohydrate levels than severely defoliated plants. In addition, it was found that plants were more likely to die when defoliated during a moderate drought than a severe drought. These differences point to management guidelines which can greatly affect farm profitability.

Some species also act as more effective nutrient pumps than others and reduce losses of nutrients through leaching (Chen et al. 1999, Scott et al. 2000). Scott et al. (2000) found that pastures based on the fertilizer-responsive deep-rooted perennial grass phalaris (*Phalaris aquatica*) and the legume white clover (*Trifolium repens*), resulted in more water use, less nitrate at depth, higher production which enabled a better than that of the phalaris (2.08) and degraded pasture (1.98) (Scott et al. 2000). This was despite the phalaris/white clover pasture containing fewer species than either of the other pastures. Some have suggested that the management of pasture species composition over the long-term requires the retention of sufficient ‘biodiversity’; this concept is explored below.

**Biodiversity** - This commonly refers only to native species and their conservation (Dyck 1996) whereas we take the broader view and include all pasture plants along with their associated biota (both agricultural and weed species). A clear link has not been reported between plant biodiversity and productivity, and little is known about how plant biodiversity affects other components of ecosystems (Wardle and Giller 1996). Even so, a tenet of conservationists is that increased biodiversity enhances ecosystem function. While Tilman et al. (1994) found that plant biomass and retention of nutrients increased in ungrazed grasslands when biodiversity increased from 1 to around 10 species, there appeared to be little benefit from higher biodiversity. The conclusions reached in these undisturbed communities are limited in their application to grazed pastures where mechanisms such as selective grazing and grazing avoidance operate.

Garnier et al. (1997) found few cases of higher productivity of multi-species assemblages compared with monocultures. Little is known about effects of plant biodiversity on soil processes and organisms (Wardle and Giller 1996). Conflicting results have been obtained on the microbial decomposition of, and nitrogen mineralisation from mono-specific litter versus litter of several species and there are no clear benefits of increasing species richness in litter above 2 species (Wardle and Giller 1996).

Conservationists tend to judge agriculture harshly when management changes natural ecosystems into agricultural ecosystems, clearing natural bushland and replacing native species with introduced species. Today, farmers are increasingly encouraged to fence unproductive areas of farmland to protect native plants from domestic grazing animals. Provided the farmer can afford it, this presents few problems. Increasingly, however, demands for nature conservation are coming from society at large; in these circumstances it would seem desirable that all of society contributes as is practised in the UK. Wilkins and Harvey (1994) suggest that agricultural production and nature conservation would be best achieved by managing separate areas of a farm, in different ways, to achieve these two objectives. In this way, appropriate grazing or cutting management for nature conservation could be achieved without compromising the parallel need to obtain sufficient agricultural productivity.

**Fertilizer** - Fertilizer applications can be used to alleviate nutrient constraints on pasture production and overcome the poor natural fertility of soils. However, there is a public perception that fertilizer use is a direct cause of increasing soil acidity. As soil acidity is linked largely to leaching events, management of
pastures to reduce leaching can minimise soil acidification. Fertilizers stimulate greater growth and allow deep rooting species to exploit their environment leading to greater water use and nutrient capture. In a summer-dominant rainfall environment, Chen et al. (1999) showed that nitrogen supply and demand in a well-nourished pasture was synchronised, with soil nitrogen being dominated by ammonium ions, such that acid forming processes were minimised. In addition to raising overall productivity, fertilizers can also be employed to promote plant persistence, change botanical composition, change quality and alter seasonal production.

Need for inputs - The idea promoted by some that continuing production can be obtained without the need to add species and fertilizers deserves particular mention. With product removal, nutrient depletion is an on-going process. As the cost-price squeeze worsens and agricultural terms of trade decline, many farmers rationalise their decision to restrict fertilizer use. There is considerable evidence of low soil fertility constraining the productivity of Australia’s pastures as documented by Wilson and Simpson (1993). Many livestock producers fail to appreciate that, as pastures are developed, the initial applications most often overcome gross nutritional deficiencies whereas later applications are primarily for maintenance. Also, it is important to recognise the feedback loop that exists between plants and fertilizers. Reduced fertilizer responses can at times be due to the loss of the more productive species from a pasture.

Grazing management - Grazing management, or the matching of grazing intensity and duration over space and time, has been reviewed recently by many authors. Lodge (1995), for example, concludes that grazing management is only justified where the stocking rate exceeds the carrying capacity of the land. The fact that considerable debate continues in the literature concerning grazing management, emphasises the fact that the interactions within grazed ecosystems are complex. Morley (1994) provides many practical suggestions concerning how to balance animal and pasture needs in grazing systems with special relevance to southern Australia. Ideally, farmers require clear guidelines for pasture and animal thresholds to assist in making decisions to move stock and/or rest pastures. Some useful guidelines are summarised by Lodge (1995).

Stocking rate and fertilizer options for sown temperate pastures

Stocking rate and fertilizer application are major determinants of animal production. With respect to desirable stocking rates, there is a trade-off between per animal performance, which can dramatically affect product quality, and per ha production which is important for financial viability. However, Seligman et al. (1989) argue that there can be no fixed optimum stocking rate for any particular situation as stocking rate and production relationships depend on input/output price ratios which change frequently. A further challenge is that any apparent optimum between stocking rate and production per head can also change with time (Gardener et al. 1990) and with level of inputs.

Hutchinson and King (1999) reviewed responses from 4 sown pasture experiments and here we have synthesised those data into a single relationship after adjustment to raw wool per ha.year to the production of Merino wethers. Responses were summarised for 56 combinations of stocking rate and annual application of single superphosphate examined in the 4 experiments cited in Hutchinson and King (1999). In spite of each experiment being conducted at different sites, when the data are presented together, they combine well within a common generic response surface between stocking rate, fertilizer application and wool production/ha (Figure 1).

![Figure 1. Relationship summarising wool production (circles) from 4 experiments as a function of the stocking rate and fertilizer treatments. Shaded areas are hypothesised domains of different sustainability. Sites: Armidale [ARM], NSW, 28oS, 980 m asl, rainfall for experimental years = 980 mm; Hamilton [HAM], Victoria, 37oS, 200 m asl, rainfall = 699 mm; Kangaroo Island [KI], South Australia, 35oS, 163 m asl, rainfall = 806 mm; and Stuart Town [STU], NSW, 32oS, 549 m asl, rainfall = 669 mm. (Adapted from Hutchinson and King 1999).](image-url)
DISCUSSION AND CONCLUSIONS

Sustainable grazing enterprises are those built on strong foundations consisting of a series of inter-related layers, each supporting the next, with long-term profit being the ultimate result. All ruminant grazing systems depend on the availability of green digestible leaf produced by persistent plants. The production of high quality leaf depends not only on climatic constraints but on factors able to be managed by the farmer – such as the pasture species present, the productive capacity of the soil as well as the level of inputs fed back from profits.

Ensuring the longevity of productive pastures is especially important; thus farmers need to recognise the importance of protecting plants at critical stages in their development. This can be more important than trying to maintain animals on that pasture without regard to pasture persistence as the cost of replacement of stock sold off in a drought is less than the cost of resowing a lost pasture.

All sustainability layers need to be monitored so that trends in animal production, pasture production, soil nutrient levels, diseases, insects, etc. can be detected and problems addressed before they become seriously limiting. In this paper, we have briefly touched on several common propositions that we suggest are myths. We question the supposed need for higher plant biodiversity in pastures, the claim that productive systems can be achieved without the replacement of nutrients with fertilizer, and that all problems can be solved with a prescriptive grazing system. It is also clear that the search for optimum stocking rates will remain elusive.

In relation to rainfall, which is of course the key driving variable, French (1987) reported a linear relationship between the potential carrying capacity of pastures and the annual rainfall across the winter wet/summer dry region of southern Australia. Although useful, the relationship is a simplification, as it fails to take into account differences in plant species, variability of rainfall, soil type and fertilizer rate.

Further work is needed to come to an understanding of the interaction between rainfall and its variability and the response surface representing the limit to sustainability as affected by stocking rate and fertilizer inputs across southern Australia.

REFERENCES


CONCLUSIONS

Research during 1940 – 1990’s provided evidence for substantial increases in grazing production from improved pastures in comparison with low grazing potential of indigenous pasture. It is noteworthy that the key features of improved pastures that promote high levels of grazing production, namely a persistent pasture legume complementing a vigorous companion grass, are the essential prerequisites for sustainability. For pastoral ecosystems, agronomic performance, grazing productivity and sustainability rely on the use of adapted species nurtured by adequate fertiliser and sustained by sound management to maintain the persistence of desirable species. Further gains to animal production and enhancement of sustainability will come from release of better adapted pasture varieties possessing increased seasonal yield performance and improvements to forage quality. However, it will be incumbent on future pasture research to not only examine effects of new practices on the grazing ecosystem at the paddock or farm level, but also to assess the wider impact on the soil, plant and livestock resources in the pastoral landscape at large.


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