WEED MANAGEMENT DIRECTIONS IN PASTURE SYSTEMS

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Summary Some two-thirds of Australia is grazed by livestock, but the pastures used by those animals for food and fibre production are often suboptimal in composition. It is rare to find a pasture without weeds. The nature of these weeds can vary from those that simply reduce productivity to those that are toxic. Weed management technology in pastures has been influenced largely by the approaches used in cropping which emphasise management of individual species and often seek short-term solutions which typically need to be repeated. The use of selective herbicides, or resowing has often been seen as the best technology for use in pastures. The main alternative to these approaches has been to introduce more aggressive pasture cultivars such as phalaris, which are more persistent and can suppress most weeds, provided fertility and management are adequate, though pasture legumes are also often suppressed. Each of these approaches does help weed management, however, such strategies will not be applicable in all circumstances. Pasture ecosystems are complex and a multi-species approach to management should offer a better chance of optimizing those mixtures than targeting a single species. Many agronomists and producers are conscious of this need, but we have not always had the required tools. This particularly applies to integrating grazing tactics with herbicides, fertilizer and over-sowing. In pastures, weed management technology arguably has to aim for optimizing the ecosystem rather than absolute control. Multi-species management requires continuous monitoring and active management for all major components, but allows some tolerance for weeds and also emphasises that desirable components cannot be 100% of the pasture. Gaps where weeds can establish will always exist and in fact are necessary to enable regeneration of desirable components. To evaluate the success, or failure of weed management technology in a pasture ecosystem different frameworks are required where management aims to keep pastures within boundaries rather than aiming for a specific ideal. This new approach is still being developed, but the concepts have started to be explored by more groups. As available land is finite we need to insure that by the beginning of the next century, we are well on the way to optimizing the sustainability and productivity of all our pasture lands.

INTRODUCTION

Pastures and weeds often seem to be synonymous terms. Across the landscape few pastures are free of less desirable components and achieve their potential for efficient, sustainable livestock production. As a consequence pasture management is inextricably tied up with weed management. Many pastures are sown, or resown to control weeds and the maintenance of productive, sustainable pastures requires continual monitoring and management of weed populations. In addition, weed management in pastures is often done primarily to minimize impact on subsequent crops, particularly in annual pasture systems. Environmental issues are particularly important with pastures as some two-thirds of the continent is used for livestock production. In recent years the role of perennial pastures in managing soil nutrients and water has become an important issue which has implications for weed control.

In this review the aim is to consider the current directions in pasture weed management research and development (R&D) and then develop a framework for weed management from the nature of pasture ecosystems. New concepts that are being developed to evaluate pasture management strategies will be considered as it is important to show that the results of research are agriculturally relevant. Consideration is given to the emphases on 'control and eradication' versus 'management and containment' in pastures as this influences the type of research done and the strategies recommended. This review will concentrate upon the weed management of pastures across southern Australia with more emphasis on the temperate perennial pasture zone and less consideration of rangelands and annual pasture ecosystems. A related review (Ewing 1996) will consider the annual pastures of southern Australia.

CURRENT WEED MANAGEMENT TECHNOLOGY

Weed management technology in pasture systems has been developed over many decades in Australia. To consider the general directions followed in recent years and the context for the work, papers presented at the last four Australian Weed Conferences were reviewed. These papers do not summarize all the work done since 1984, but do serve to indicate the general emphases in R&D. The issues discussed in perennial and annual pasture systems are summarized in Table 1. This summary table does not include work on herbicides for specific species out of a pasture context, or some papers that had a general application to pastures.

Developments in weed management technology for pastures largely fall into a few main groups. Over recent years there has been a clear interest in general problems of weeds in pastures, impact assessment, economics, policy and a start on developing decision support systems to better manage weeds. Often though, the decision support systems have been restricted to optimizing herbicide use and have not yet developed to take a broad view of pasture weed management. Weed management in perennial pastures and rangelands can be considered as management of the total vegetation yet little seems to have been done to develop such an approach for perennial pastures that has been adequately researched and then implemented on properties. Pasture weed management seems to be simply copied from the methods used in cropping systems and it is uncertain if that is always appropriate. Pleas have often been made for better data on weed distribution and density to enable more objective appraisals of impact and the consideration of management options (Auld 1984), but only limited progress would appear to have been made.

Table 1. Pasture weed management issues discussed at the 7th, 8th, 9th and 10th Australian Weed Conferences. Number of papers on perennial (rangeland) and annual pasture systems.

Issues discussed	Perennial (Range)	Annual
General		
Impact, spread, management	12	
Economics	4	
Research/Public policy	11	
Decision support systems	7	
Control of specific weeds		
Biology, ecology	10 (6)	12
Competition	3	3
Herbicides	27 (10)	8
Herbicide resistance	2	14
Herbicides, non-target species	4	6
Biocontrol – classical	31 (9)	7
Biocontrol – augmented	6	1
Grazing – goats	9 (1)	0
Grazing – other species	1	2
Burning	3 (3)	0
Cultural practices	0	0
Allelopathy – from weed	1	3
Allelopathy – to weed	0	0
Weed toxicities	1	0
Integrated weed management	1	4

The work presented in past conferences on major topics, in part reflects the major symposia that have been held, which is also a reflection of the major interest in those areas of work. The R&D done usually relates to individual species. The numbers of papers in relation to species is summarized in Table 2. Table 2 includes papers on herbicides for specific weeds.

This list of species indicates a shift in emphasis from a decade earlier (Blacklow *et al.* 1984). Species like serrated tussock (*Nassella trichotoma* (Nees) Arech.) do not appear on this list probably because they had been the subject of earlier R&D and no new developments were occurring. The species of most interest are clearly annual grasses and thistles, with less emphasis on perennial grass weeds.

Biology Current interest in the biology and ecology of weeds points to a clear interest in understanding important and emerging weeds, reflecting the benefits (Dodd 1990, Groves 1992, Briese 1993) from such work. This particularly applies in the rangelands (60% of papers) compared with other perennial pasture ecosystems, as smarter management tactics are among the few options available in the former. The options available to

Table 2. Number of papers on species, or species groups in pasture systems presented at the 7th, 8th, 9th and 10th Australian Weed Conferences.

Species	No.
Annual grasses (*Vulpia* spp., *Bromus* spp., *Hordeum* spp., *Lolium* spp.)	45
Thistles (*Carduus* spp., *Onopordum* spp., *Carthamus* spp.)	13
Paterson's curse (*Echium plantagineum* L.)	3
Burrs (*Xanthium* spp.)	4
St. John's wort (*Hypericum perforatum* L.)	5
Blackberry (*Rubus* spp.)	6
Horehound (*Marrubium vulgare* L.)	3
Common heliotrope (*Heliotropeum europaeum* L.)	2
Spiny emex (*Emex australis* Steinh.)	4
Cape weed (*Arctotheca calendula* (L.) Levyns)	2
Skeleton weed (*Chondrilla juncea* L.)	3
Silverleaf nightshade (*Solanum elaeagnifolium* Cav.)	3
Fireweed (*Senecio madagascariensis* Poiret)	4
Ragwort (*Senecio* spp.)	2
Perennial grasses and sedges (inc. *Eragrostis* spp., *Poa* spp., *Sporobolus* spp., *Imperata* spp.)	11
Miscellaneous broadleaf weeds	7
Pasture legumes (*Trifolium* spp.)	5
Perennial pasture grasses (*Phalaris aquatica* L.), *Themeda australis* (R.Br.) Stapf, *Lolium* spp.)	5

producers are often limited to herbicides or resowing. The emphasis in annual pastures often reflects the desire to control weeds for subsequent crops rather than to improve the efficiency, or productivity of pastures (Leys 1990).

The mechanisms whereby weeds compete with more desirable components in a pasture have received very little attention. Tactics to manipulate species among the annual grasses are only just starting to be explored (Leys 1990). One of the more recent studies has demonstrated that vulpia can be reduced to a low level if it is replaced with annual ryegrass, which is less of a problem for pastures (Leys *et al*. 1993). Annual ryegrass competes for similar resources to vulpia and is then more effective as a competitor than subterranean clover (*Trifolium subterraneum* L.). Other studies have shown that weeds do not necessarily achieve ecological success because they are the most competitive species in the pasture. Spiny emex is a weak competitor against subterranean clover and *Hordeum glaucum* Steudel, hence resowing pasture species after cropping rather than relying on natural regeneration, will provide increased competition and help to manage the weed (Panetta and Randall 1990). Analysis of naturalized grasslands has suggested ways of limiting further invasion by weed species and helped define the varying impact of exotic species (McIntyre 1993).

For most species there are large gaps in our understanding of how they persist in pasture ecosystems. Without such information it is difficult to develop alternative, integrated practices that encourage the desirable species while managing the less desirable. Techniques are available for the study of population dynamics in pastures, but it has not been easy to convince funding bodies of the importance of these more basic studies. However, it is now time to do such work if we are going to build better, more effective weed management systems for pastures. To some degree the easy work of finding a method to control weeds has been done, but the fact that many pastures still contain weeds suggests we need to develop alternative weed management methods that producers consider are more relevant to them.

Herbicides Herbicides are a major interest, reflecting the large amount spent each year on their use. They have been a valuable tool in pastures over the years, particularly where other methods of weed control have shown little benefit. Recent emphases on herbicide technology have been aimed at selective removal of weeds, or total vegetation control to enable resowing of pastures. There have been limited studies on non-target species and this has usually been about direct effects on growth, or yield rather than longer-term consequences on the pasture ecosystem. For example, does the use of herbicides predispose the pasture to subsequent invasions? What are the conditions to minimize such effects? There is arguably more work being done on herbicide tolerance of wheat than all pasture species combined. Does this suggest that herbicides are seen as having a limited role in pastures? It is interesting to note that herbicides are considered in rangelands to be a useful tool—usually this is in northern Australia and reflects the strongly competitive abilities of many invading species (Brown and McIvor 1993) and a desire to limit the spread of potentially disastrous species even though the cost could be considered uneconomic at the site of application.

One of the difficulties with herbicides in pasture systems is the need for selective removal of weeds from within pastures at low cost (Campbell *et al.* 1984). Often the requirement is to select among very closely related species or genera, e.g. selective removal of annual grasses is also likely to remove any desirable perennial grass seedlings—an extreme case being among *Lolium* species. There is a continuing search for selective chemicals as it could be argued that they are still not selective enough. However, increasing selectivity could also mean smaller markets for products and hence less incentive for their development. Current selective herbicides often result in lost production from the desirable components and lost opportunities for seed set and/or seedling recruitment of those species (Dear and England 1987). Work with these herbicides does need to emphasise optimal performance within pastures but little work seems to have been done to develop strategies following use of selective herbicides that encourage the desirable components in a pasture. The lack of emphasis on integrated techniques with herbicides (Wolf 1984 considers the 'science' of weed control is all about herbicides, or biotechnology) has often been evident.

Spray-graze tactics are a successful part of our armoury for pasture weeds like Paterson's curse. However it is also evident that such tactics do not always include additional practices to encourage regeneration of desirable components such as tactical rests to allow seed set and/or seedling recruitment.

The number of papers discussing herbicide usage in pasture systems is arguably a gross underestimate of the R&D activity as it does not include earlier work on established practices such as use of 2,4-D on thistles, or Paterson's curse, herbicide developments, or application technology. A lot more has also been done on annual pastures, but those additional papers were not considered here, as their main emphasis was on controlling vegetation for the cropping phase. The emphasis on implications for cropping is further reflected in the papers on herbicide resistance where the driving force would appear to be management of resistance in annual pastures to sustain crop productivity. Very little has been done about the level, or management of herbicide resistance in perennial pastures, though present indications are that it is low (Powles, Pratley personal communication).

Herbicide resistance in annual pastures has been well researched, achieving a good understanding of the problem and within a short time proposing tactics for management (Powles 1987). Management of herbicide resistance now involves rotation of herbicide groups (Powles and Holtum 1990), use of combinations of herbicides and tactics that reduce the seed population of resistant weeds. It would seem that such tactics would also work in perennial pastures, but they have not been trialled as yet.

The use of herbicides to control annual grasses in annual pastures is becoming a well developed tactic (Leys 1990). An issue with such tactics that does not seem to have received much attention is the stability of the resultant pasture. A mono-specific, legume dominant pasture does require careful management to be effectively utilized and may only have an effective life of one year. Associated practices need to manage the nitrogen in the system, usually through cropping, and minimize erosion risks, while additional herbicides may be needed to control nitrophilous weeds.

Biological control Australia is a world leader in the use of biological control for weeds. This has been accepted as a valuable management tool, though usually retroactively rather than pro-actively (Cullen and Delfosse 1990) which necessitates catch-up management rather than acting before a problem becomes massive. The emphasis in biological control has clearly been in perennial pasture systems, including rangelands. This emphasis fits with the idea that management in these systems needs to have a range of options, whereas in annual pastures the weeds can often be controlled as part of the cropping cycle. Only difficult weeds like skeleton weed (Groves 1984) have received a lot of attention for biocontrol in annual pastures—other important weeds in annual systems, such as Paterson’s curse, have biocontrol programs focused more on their impact in perennial pastures.

Over the last decade ‘augmented’ or ‘assisted’, biological control has started to emerge as an important new tool. Mycoherbicides have been developed commercially (Templeton 1987) and others are in the process. It is to be expected that the boundaries between ‘classical’ and ‘augmented’ biological control will blur as efforts are made to make better use of less spectacular agents. Biological control R&D is being backed by biological and ecological studies, which is not necessarily the case with other management tools. The emphasis is shifting towards a more phytocentric approach (Briese 1993) involving multi-disciplinary teams where the control agent is viewed as one component of the weed’s life system.

Integration of biological control with other weed management tactics is only starting to receive some attention, but promising new possibilities are emerging (Briese 1993). The toxicities of herbicides to control agents has been studied (Wright and Skilling 1987), while synergistic effects between herbicides and pathogens are being explored (Auld 1995). The integration of other techniques with biocontrol is not only important for providing a range of options, but also for understanding ways of enhancing the performance of biocontrol agents.

Grazing Grazing can be considered part of biological control, but with the added advantage that the weeds can be converted into livestock products. The context for such a strategy was recently summarized (Popay and Field 1992) and requires an important shift from focusing on the animal, as done by most producers, to weed control and pasture management being the main aims. In some circumstances this can cause a temporary loss in animal output.

Most studies on weed control through grazing tactics have involved the use of goats (Campbell and Holst 1987). Goats have a long history of use for weed control, even though it is likely that sheep do more weed control on Australian dryland farms (Amor 1987). It is a pity that the goat industry has not developed to a higher level to encourage wider use of these valuable animals. Goats have particular advantages over sheep and cattle for the management of more fibrous and thorny weeds. Unfortunately little seems to have been done on better use of sheep and cattle for pasture management and weed control. Their impact on weeds may not be as spectacular as goats, but they can still be important (Beattie 1994). Grazing management also needs to consider ways of limiting the spread of weed seeds by livestock (Heap and Honan 1993).

The use of sheep and cattle for weed management may require a different approach to that used with goats. To maximize the effectiveness of grazing tactics it may first be necessary to manipulate the weed into a more susceptible state, or change its development pattern. Recent work with barley grass (*Hordeum leporinum* Link) in central New South Wales (Kemp *et al*. 1995), showed that a rest from grazing during winter in an annual pasture, encouraged a more upright growth habit of the barley grass, which raised the level of the apex making it vulnerable to removal by sheep. Plants were grazed before seed heads emerged and it became unpalatable. This treatment also doubled the legume content of the pasture making it more attractive to livestock. Grazing off the pasture at the end of August achieved the same control of barley grass in the following year as herbicide (carbetamide). In bent grass pastures in Victoria better management has been achieved with the use of a herbicide (glyphosate) to limit reproductive development which then made the pasture more attractive to sheep and turned a 'weed' into a 'resource' (Hill 1995).

Other practices Weed management with cultural practices in pasture systems has not received any attention over recent years. The use of mechanical treatments such as cultivation, slashing, ripping etc., for weed control augmented by fertilizer or grazing practices, is rarely mentioned. The limited R&D is interesting given that producers still use slashers, usually after seed set by thistles, and there is a continuing debate about the benefits of 'agro-ploughs' and 'soil aeration'. Variable results with these tools probably reflect the timing of their use and the composition of the pasture. The use of nitrate fertilizers to stimulate thistle seed germination and enable better control was demonstrated many years ago (Michael 1970), but this has not yet been adapted into management practices.

Burning is established as a technique in rangelands and one of the few options available for woody weed control. It has also proved of use in higher rainfall pasture ecosystems (Lodge and Whalley 1989) but seems to be rarely considered among weed management tools. New approaches could be developed with burning using light fuel loads that could differentially affect species. This would reduce the need to wait for the right seasonal conditions to apply this technique.

Allelopathy and toxicities Some plants are weeds because they are toxic to other plants, or to animals. This aspect of weed biology is of continuing interest. The emphasis in allelopathy R&D tends to be on effects in annual pasture/cropping systems and implications for the crop rather than for the pasture. Allelopathy can be a significant problem for regenerating pasture species like subterranean clover (Leigh *et al*. 1995), but the full implications and interactions with weeds are not known. Little has been discussed to date about reversing that process, i.e. to use allelopathic effects against weeds as a management tool, though it is an area of interest (Lovett 1990). The management of toxic weeds to minimize their effects has usually been more about controlling the weed than utilizing it as a resource with minimal side effects. St. John's wort would be a candidate for such a strategy i.e. similar to the use of rumen micro flora to detoxify *Leucaena* spp. The metabolic reasons why goats seem less affected by St. John's wort than sheep have received little study.

Integrated weed management With many tools for weed management available it is quite noticeable that few published studies refer to integrating strategies in pastures. Where this has been done it has usually been to integrate weed control in annual pastures with cropping activities. Over the years reviews have mentioned the need to integrate tactics (Blacklow *et al*. 1984, Kon 1993) but this is rarely picked up in studies. Many papers do not indicate how the work done would fit into a broader ecosystem, or farming system context (Pannell 1987). One suspects this reflects an overall emphasis on control/eradication rather than management of an integrated ecosystem. Surveys (Dowling *et al.* 1993), have shown that producers recognise the need for better overall management to control weeds, while the impact of herbicide resistance is making integrated strategies almost mandatory (Gill 1993). Land managers have also expressed a desire to reduce herbicide usage (Wilson 1993).

Where integrated strategies have been discussed it has usually been in relation to existing problems. Very little has been done about developing a pro-active approach to limit the opportunities for weed spread, or for the early recognition of species that may become the next important weed problem (Hobbs 1993).

The difficulties in developing integrated strategies are illustrated by Campbell and Dellow (1984). They showed the relative importance of insects and livestock for management of St. John's wort. Best results were from an initial knockdown with insects followed by heavy grazing with animals, though they concluded that the best grazing technique has yet to be devised. The ability of annual legumes to compete with the weed and smother weed seedlings, suggests that grazing tactics should aim to minimize selective removal of the legume. This could be done with a rotational grazing system that limited opportunities for selectivity, over autumn to early spring, but this has not yet been tried. Like many temperate species, St. John's wort starts flowering in spring and is then at its most vulnerable. Exerting extra grazing pressure in spring is not always easy and can really only be done on a paddock basis by combining animal groups. Once the weed population had been reduced insect damage was very slight, presumably due to the difficulties then posed to insect reproduction and distribution. With St. John's wort it is difficult to maintain heavy grazing so that animals consume the weed without severe effects on livestock performance. The exception is with goats grazing pasture with a low density of St. John's wort. This work on St. John's wort suggests that management strategies will need to accept some residual population and use a combination of insects, fertilizer, grazing tactics and livestock types to keep the weed in check.

Many integrated weed management strategies aim to improve the competitiveness of desirable species against the less desirable. However that is not applicable in all circumstances. Rangeland studies are now suggesting that management may be more effective by emphasizing limiting the dispersal of invading plants and implementing more complex management regimes that are based on the negative effects of disturbance on invaders (Brown and McIvor 1993). In this case grasses may be of most use for creating fuel which can help burn invading shrubs than directly competing with shrub species seedlings. This approach often carries the implication that it is more economic in the long term to control competitive weeds at the sites where they first invade even though an economic return for that effort may be negative in terms of increased productivity at the control site. The benefits are from minimizing longer term problems and costs.

CONCLUSIONS

This brief overview of the directions in current weed management does suggest that in pasture systems R&D is still more concerned with 'control/eradication' than 'management/containment', a point very obvious in the title for the 1992 International Weed Control Congress. This may arise from the emphasis in many cropping systems of trying to eliminate weeds, whereas as will be discussed later, tolerance may be more appropriate in pasture systems. Papers presented at the 1992 International Weed Control Congress had similar themes to those at the Australian Weeds Conferences. There was overwhelming interest in herbicides and the other topics listed in Table 1. There were encouraging papers (Groves 1992) which showed how the science of weed control was developing techniques to be pro-active and identify potential weeds, with the plea for the formulation of prospective control plans. Pasture systems received very little attention at that Congress which indicates either that pastures do not have weed problems, or that we need to develop a new approach to thinking about weed management within them.

A FRAMEWORK FOR PASTURE WEED MANAGEMENT

To develop better weed management practices for pastures the differences between pastures and crops need to be considered. Often producers have been urged to treat a pasture as a crop. There is some validity in that approach, especially where the pasture is the product, e.g. lucerne hay. However a consequence is the expectation that a 'good' pasture should be like a mono-culture, which is not realistic or desirable. Pastures are ecosystems and need to be managed as such.

What is a pasture? This question may seem obvious, but it does influence the way we think about pasture management. In broad terms a pasture is a community of plants that are grazed by animals. These can vary from cattle and sheep to goats and kangaroos, depending upon the aim of an enterprise. (A likely emerging area could be the maintenance of grazing for marsupials, within natural resource areas—a system we know little about.) Pastures are derived from a variety of sources, from those dominated by native species, to newly sown mixtures of introduced species.

The majority of pastures are naturalized mixtures (Kemp and Dowling 1991, Quigley 1991) where a high proportion of the sward is volunteer species. Such pastures change in composition over time. These naturalized pastures may have started from either a native, or sown mixture. The invading species can be either desirable or not, for livestock production. In annual pastures in particular, we rely on desirable species naturally regenerating every year. In temperate perennial pastures there is evidence for invasion and regeneration of useful native grasses within pastures originally sown to introduced species (Kemp and Dowling, unpublished). The annual regeneration of subterranean clover drives many pastures.

The fact that we rely on a reasonable proportion of most pastures to regenerate naturally, often annually, predisposes the pasture to invasion. The obvious exceptions to this are old phalaris and kikuyu dominant pastures and limited, unfertilized native grass pastures. At the other end of the spectrum we can of course, have pastures dominated by undesirable species such as serrated tussock which do not allow invasion from other species.

Unfortunately there is still the perception that you can sow a pasture and, with minimal management, it will be there forever. All too often strong, stable pastures are though, a minor part of the total area of pasture. These attitudes are reflected in the desire and search for pasture cultivars that will withstand all abuse and keep weeds out forever. The emerging view with pasture species is that they all have weaknesses and to realise their potential all need appropriate management.

Pastures are a mixture of species with different roles. In temperate perennial pastures the better 'base' for a pasture is a perennial grass. Legumes are required to put some nitrogen in the system, the exact proportion depending upon the stage of development of the pasture and soil fertility. A good perennial grass base will help utilize the soil nitrogen and provide stability in the system.

Perennial grasses and legumes will not however, occupy all the 'resource space' within a pasture. Resource 'gaps' will develop that can be exploited by other species. These are the sites where weeds invade. The better way to utilize these gaps may be to manage the pasture to encourage species with some utility to fill those gaps. Such species would include some broadleaf species and annual grasses. The aim in pasture management is then not to remove such species, but to contain them as a low proportion of the pasture to limit invasion by less desirable species. In comparison with the control/eradication approach taken in cropping systems, better weed management in pastures can be 'imperfect'. The exception is with weed species that are considered to be highly competitive, have no utility for livestock and which could not be easily contained at a low level within the sward.

Weed invasion in pastures Weed management in pastures often reflects a range of responses, from 'how did that get there!' to 'the only solution is to dig it all up and start again'. There often seems to be little realisation that we are dealing with ecosystems that are in a state of flux. We expect pasture species to be aggressive and regenerate in the face of considerable competition from other species—in terms of the early views of ecology, they are early successional species. These are among the characteristics of weeds. The environment we create in a pasture is then one for weed invasion, except that we hope the 'weed' that invades is one we want or can use. The weed flora in pastures is often changing (Kloot 1987) due to regular opportunities for recruitment and the changing nature of the resources available for plants to exploit. To manage these changes it is necessary to think in terms of the ecological niches that become vacant where weeds can invade. If those niches are kept small then weed problems are likely to be minimal.

Weed invasion in pastures is further reinforced by grazing and other management practices. Animals are selective and favour some species over others. This lessens the competitiveness of desirable components and provides 'space' for weeds. Many desirable pasture species have been selected for rapid growth rates, which invariably requires adequate mineral nutrition. If soil fertility declines, this provides a niche for less demanding weed species to invade. When soil fertility is high, especially the soil nitrogen content, this allows invasion from nitrophilous species.

The management of weeds in pastures does need to take an ecological approach and look at how the performance of the mixture of desirable components can be optimized to limit the invasion, or proportion of weeds. In contrast the more common approach often seems to be to react to an immediate problem, look for a chemical that will take it out then continue until the next crisis. In reality eradication of many weeds is not feasible (Dodd 1990).

What are the main weed problems in perennial pastures? The main weed problems in pastures are often those that cause production losses directly through affects on animal grazing and toxicity, e.g. thistles restricting access, Paterson's curse being toxic or indirectly from reducing the productivity of the better pasture components (e.g. annual grasses or thistles), reducing the resources available for perennial grasses. Often a combination of effects applies.

In the few surveys of the composition of pastures (Moore 1970, Kemp and Dowling 1991, Quigley 1991), annual grasses originally introduced from the Mediterranean (e.g. vulpia, *Vulpia* spp.; barley grasses, *Hordeum* spp.; annual ryegrass, *Lolium rigidum* Gaud.; and bromes, *Bromus* spp.), are often major components. These species occur at most sites surveyed and are arguably the major weed problem in pastures. They are though, of mixed effects as during winter they often provide useful forage and some, e.g. the bromes, are less of a problem than others. Managing such species in pastures should aim to reduce the proportion of the more troublesome in the sward to a low level and shift the balance to more desirable species such as soft brome (*Bromus molliformis* F.E. Lloyd).

Paterson's curse can be utilized as forage (Piggin 1977), but like thistles that utility is probably marginal against the costs they inflict on overall pasture and livestock productivity. However as discussed earlier, the optimal integrated strategies for these species have not yet been devised.

In pastures the concepts of functional groups needs to be developed. Plants compete for resources and in many cases more than one species is competing for the same resources. There is a need to identify the resources that a weed is competing for and then reduce its availability. Management of that weed should not leave those resources unused else another species will readily fill the gap. We need a pro-active approach to pre-empt weed problems.

Principles for pasture and weed management The management of pastures to minimize weed impact should involve strategies that aim to manage the major components. This multi-species approach would have several goals:

- Maintain the perennial grass component within lower and upper limits. The lower limit is important to preserve the species within the pasture and the upper to limit dominance which could preclude other useful components, or induce instabilities in the ecosystem.
- Maintain the legume content within lower and upper limits. The lower limit is important to sustain

nitrogen input to the pasture and provide some quality forage for livestock, while the upper limit is to improve stability in the pasture. A legume dominant sward can prove difficult to manage—as even occurs with well managed lucerne pastures—and cause bloat problems.
- Weeds with some utility such as annual grasses, need to be contained below some upper limit in order to maximize the resources available for perennial grasses and/or legumes. The same would apply to palatable broadleaf species not considered major weed problems. These species often quickly exploit 'resource gaps' and this ability can be used to limit invasion by less desirable species.
- Weeds with little utility for livestock, that can form a significant proportion of the pasture need to be controlled to a very low level. This often involves additional tactics that can enhance the performance of the desirable pasture components, e.g. herbicides, oversowing and/or fertilizer applications.

The range between lower and upper limits for perennial grasses and legumes is that required to obtain optimum pasture growth rates and intake by livestock. Limits can be defined in a range of units, e.g. per cent dry weight, ratios between components or absolute yield. The tools available to manage multi-species pastures involve grazing, herbicides, biocontrol, fertilizers and other tactics. As discussed earlier there has been considerable research on each component, but little on their integration.

These principles together emphasise the need for integrated multi-species management and an ecosystem approach as the aim shifts from one of control/eradication to management/containment for most of the species commonly found in pastures. When this approach is used different procedures are needed to evaluate the significance and benefits of management practices than simple analyses of variance, and to indicate to producers how to optimize the performance of their pastures. More use needs to be made of multi-variate procedures in the analysis of pasture weed management than has been the case to date. Techniques to better understand and detect significant differences between multi-variate components are available (Klein, Nicol and Kemp unpublished).

Evaluation of pasture management treatments New approaches are needed to summarize research results and provide messages for producers. The state and transition models developed for management of rangelands (Westoby *et al.* 1989) are now being applied for weed management (MacLeod *et al.* 1993). These models consider the likely stable 'states' that a system can exist in and the influences that produce 'transitions' between them. An aspect of these models is the emphasis on when management is needed and when it may have limited impact, as well as the probabilities of moving between different states. The later is important as it may not be possible to shift between different states under normal management practices.

One limitation of the current state and transition models is that it can be difficult to simply impose research results on them, some interpretation is needed. It can also be difficult to define states for some pasture ecosystems as the data on species interactions can show a continuous distribution with no 'phase' changes (Kemp *et al.* unpublished). These difficulties have been addressed for temperate perennial pastures using a 'species matrix' model (Figure 1; Kemp, Michalk, Dowling and Klein unpublished). An important part of this approach is to group species in 'functional groups'. For perennial pasture ecosystems there are usually four main functional groups – annual and perennial grasses, legumes and broadleaf weeds. The species matrix involves calculating two ratios—one between perennial grasses and annual grasses, the other between legumes and broadleaf weeds—and then plotting the two ratios against one another. Emphasis is on the desirable : less-desirable species ratios. The pasture is then defined in four states of a 2 × 2 matrix—annual, or perennial grasses with broadleaf weeds, or legumes. At this stage pastures are considered to change states when the ratios exceed 1. This will be refined with further work.

The species matrix can illustrate changes in pasture composition and show the effect of management practices. It is important to show that a weed management practice does improve the overall composition of the pasture and moves it into a desirable state and not, for instance, control the annual grasses, but still leave other weeds present and not change the perennial grass components.

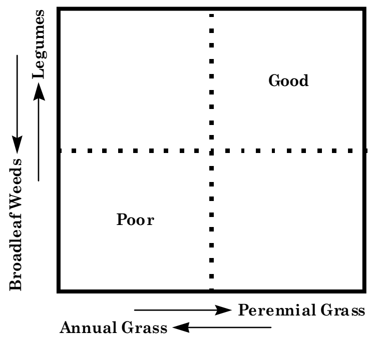

Figure 1. Species matrix showing the four common 'states' for temperate perennial pastures. The dotted lines indicate where the ratio between the relevant functional groups equals 1.

For livestock production the quantity of useful biomass is also important. The 'pasture management envelope' (Kemp and Michalk 1994) based on an approach taken for the management of tropical pasture experiments (Spain *et al*. 1985) considers the upper and lower limits for a key species against the amount of (green) biomass available. Upper and lower limits on biomass are defined to optimize pasture growth and animal intake. The criteria used are similar to the benchmarks that feature in advisory programs such as Prograze (Allan 1994). The results from treatments can then be plotted against these criteria (Kemp *et al*. 1996).

Results from studies on pasture weed management need to be evaluated against techniques such as the species matrix, or pasture management envelope, to establish if the results are agriculturally important. A conventional analysis of variance may show statistically significant differences between treatments, but this may still only be for example; a reduction in weeds to 70%, or a rise in perennial grasses to 15%, or that the available forage for livestock never exceeds 0.5 t DM ha^{-1}. An example with the pasture management envelope showed that use of a herbicide for annual grass control in a degraded cocksfoot pasture did not achieve a desirable increase in the cocksfoot, or in the biomass available for livestock, even though there was a highly significant control of the annual grasses (Kemp *et al*. 1996). Results do need to be judged against appropriate criteria. Very little has been done on bio-economic modelling, an area that should have increasing emphasis.

DISCUSSION

Weed management technology in pasture systems has changed over the years. It is about time though, there was more acknowledgment that weed management in pastures, particularly perennial systems has different emphases from cropping. In crops, control and ideally complete removal of the weed is still a goal, whereas in pastures keeping weeds to a minimum and a multi-species management approach is more realistic.

In the past there was an emphasis on individual weed management tactics, often in isolation from other practices. That emphasis is still there, but there is an increasing interest in integrated strategies and their proper evaluation in both a scientific and agricultural context. Advances in the future may come more from developing that integrated approach than from any one individual tactic. In following that path though, there is a range of issues that need to be considered:

- Predictability and practice—can we predict the next weed to emerge in a paddock, which niche will it occupy and what will its characteristics be? Can we plan a strategy that will manage weeds in functional groups (as partially done with annual grasses) and limit new weeds emerging?
- Paddock versus property management. Where should we put our emphasis? Cropping systems weed management is usually thought of from a paddock perspective, but for some strange reason pastures are seen as requiring the same practice to the whole property at the same time!
- Herbicide research is of major importance, but few papers have tried to link herbicide developments, use, resistance and residues in context, particularly for perennial pasture ecosystems.
- The development of herbicide resistant pasture cultivars has received almost no discussion at Australian Weed Conferences. This is a pity as the context for such a development is different to that for crops. As discussed earlier, pasture plants are usually selected to be early successional, invasive species in order to compete with weeds and re-establish after disturbances. What are the costs if herbicide resistance is included, particularly to broad spectrum chemicals? We need a reasoned analysis from a range of perspectives before embarking on such developments. Unfortunately a recent meeting on this issue (Anon. 1995) was mostly concerned with crops.
- What is the likelihood of 'agriculturally useful' species like pasture plants becoming weeds (Lonsdale 1994) given we often expect these species to regenerate naturally. With pastures there is a significant gray area that will become increasingly important as we aim for sustainable systems in better harmony with needs for biodiversity. What are the implications for pasture and weed management? Does this mean we may be limited in the species we can introduce in the future and hence have to learn more about managing those already in use.
- In perennial pasture ecosystems weed management needs to be considered in the context of sustainability. This context means seeking more subtle solutions that minimize intervention and disturbance to the ecosystem as we aim to shift the composition towards desirable ends. Pastures can have a role in the maintenance of biodiversity.
- The National Weeds Strategy promotes integrated practices within the principles of ecologically sustainable development though, little emphasis is placed upon the weeds that cause major production losses in pasture systems. Public policies should encourage the development of weed management tactics and strategies that fit within an integrated approach.

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REFERENCES

Allan, C.A. (1994). Prograze. NSW Agriculture Agdex 400/16.

Amor, R.L. (1987). Non-chemical weed control in Victorian dryland crops—the dream and the reality. Proceedings 8th Australian Weeds Conference, pp. 348-51.

Anon. (1995). Proceedings of the workshop on 'The role of herbicide-resistant crops and pastures in Australian Agriculture'. (Bureau of Resource Science, Canberra).

Auld, B.A. (1984). Weed distribution. Proceedings 7th Australian Weeds Conference 1, 173-6.

Auld, B.A. (1995). Selective control of Noogoora burr or cocklebur. Patent No: 6290, Australia.

Beattie, A.S. (1994). Grazing for pasture management in the high-rainfall perennial pasture zone of Australia. *In* 'Pasture Management: technology for the 21st century', eds. D.R. Kemp and D.L. Michalk, pp. 62-70. (CSIRO, Melbourne).

Blacklow, W.M., Pearce, G.A. and Humphries, A.W. (1984). Allocating scarce resources to research on weeds and their control in Australia. Proceedings 7th Australian Weeds Conference 2, 90-107.

Briese, D.T. (1993). The contribution of plant biology and ecology to the biological control of weeds. Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 10-8.

Brown, J.R. and McIvor, J.G. (1993). Ecology of woody weed invasions in the tropical woodlands of north-eastern Australia: implications for management. Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 471-4.

Campbell, M.H. and Dellow, J.J. (1984). Control of St. John's wort (*Hypericum perforatum*) by insects and/or grazing animals. Proceedings 7th Australian Weeds Conference 1, 109-12.

Campbell, M.H., Dellow, J.J., Kemp, H.W. and Keys, M.J. (1984). Selective removal of *Eragrostis curvula* from *Phalaris aquatica* and *Pennisetum clandestinum*. Proceedings 7th Australian Weeds Conference 1, 354.

Campbell, M.H. and Holst, P.J. (1987). Control of Illyrian thistle, *Onopordum illyricum* by goats. Proceedings 8th Australian Weeds Conference, pp. 24-6.

Cullen, J.M. and Delfosse, E.S. (1990). Progress and prospects in biological control of weeds. Proceedings 9th Australian Weeds Conference, pp. 452-76.

Dear, B.S. and England, P.J. (1987). The effect of pasture topping on weed control and herbage production and seed set of subterranean clover. Proceedings 8th Australian Weeds Conference, pp. 17-20.

Dodd, J. (1990). The role of ecological studies in assessing weed eradication programs. Proceedings 9th Australian Weeds Conference, pp. 416-26.

Dowling, P.M., Leys, A.R. and Plater, B. (1993). Management practices associated with increase of vulpia in pastures—a survey. Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 193-7.

Ewing, M. (1996). Assessment of the outcomes of weed management technology in cropping zone pasture systems. Proceedings 11th Australian Weeds Conference, Melbourne, pp. 264-9.

Gill, G.S. (1993). Development of herbicide resistance in annual ryegrass in the cropping belt of Western Australia. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 282-5.

Groves, R.H. (1984). Ecological control of skeleton weed in south-eastern Australia—past, present and future research. Proceedings 7th Australian Weeds Conference 1, 125-8.

Groves, R.H. (1992). Weed ecology, biology and spread. Proceedings 1st International Weed Control Congress 1, 83-8.

Heap, J.W. and Honan, I. (1993). Weed seed excretion by sheep—temporal patterns and germinability. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 431-4.

Hill, R. (1995). Managing pastures in a bent grass environment. Agriculture Victoria bulletin.

Hobbs, J. (1993). Dynamics of weed invasion: implications for control. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 461-5.

Kemp, D.R. and Dowling, P.M. (1991). Species distribution within improved pastures over central NSW in relation to rainfall and altitude. *Australian Journal of Agricultural Research* 42, 647-59.

Kemp, D.R. and Michalk, D.L. (eds.) (1994). 'Pasture Management: Technology for the 21st Century', pp. 177. (CSIRO, Melbourne).

Kemp, D.R., Michalk, D.L. and Dowling, P.M. (1995). Managing pastures to improve composition and quality. Proceedings 36th Annual Conference, Grasslands Society of Victoria., pp. 113-23.

Kemp, D.R., Michalk, D.L., Dowling, P.M. and Klein, T.A. (1996). Improving pasture composition by grazing management in relation to a management envelope. Proceedings 8th Australian Agronomy Conference, pp. 345-8.

Kloot, P.M. (1987). The changing weed flora of Australia. Proceedings 8th Australian Weeds Conference, pp. 134-47.

Kon, K.F. (1993). Weed management: towards tomorrow. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 1-9.

Leigh, J.H., Halsall, D.M. and Holgate, M.D. (1995). The role of allelopathy in legume decline in pastures. I. Effects of pasture and crop residues on germination and survival of subterranean clover in the field and nursery. *Australian Journal of Agricultural Research* 46, 179-88.

Leys, A.R. (1990). Control of annual grasses in pastures of southern Australia and implications for agriculture. Proceedings 9th Australian Weeds Conference, pp. 354-64.

Leys, A.R., Dowling, P.M. and Plater, B. (1993). The effect of pasture density and composition on vulpia. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 190-2.

Lodge, G.M. and Whalley, R.D.B. (1989). Native and natural pastures on the northern slopes and tablelands of New South Wales. NSW Agriculture, Technical Bulletin 35.

Lonsdale, W.M. (1994). Inviting trouble: introduced pasture species in northern Australia. *Australian Journal of Ecology* 19, 345-54.

Lovett, J.V. (1990). Chemicals in plant protection: is there a natural alternative? *In* 'Alternatives to Chemical Control of Weeds', eds. C.A. Bassett, L.J. Whitehouse and J.A. Zabkiewicz, pp. 57-65, New Zealand Ministry of Forestry, FRI Bulletin 155.

MacLeod, N.D., Brown, J.R. and Noble, J.C. (1993). Ecological and economic considerations for the management of shrub encroachment in Australian rangelands. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 2, 118-21.

McIntyre, S. (1993). The nature of exotic invasions in herbaceous vegetation of high and low species richness: implications for conservation and management. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 466-70.

Michael, P.W. (1970). Biology and ecology of thistles. Proceedings of the Weed Science Society of New South Wales, pp. 3-6.

Moore, R.M. (1970). Australian grasslands. *In* 'Australian Grasslands', ed. R.M. Moore, pp. 85-100. (Australian National University, Canberra).

Panetta, F.D. and Randall, R.P. (1990). Competitive effect and response of *Emex australis* in a grazed annual pasture. Proceedings 9th Australian Weeds Conference, pp. 365-8.

Pannell, D. (1987). Weed control economics research in Australia. Proceedings 8th Australian Weeds Conference, pp. 1-11.

Peirce, J.R. (1987). The use of goats for control of saffron thistle, *Carthamus lanatus* L. Proceedings 8th Australian Weeds Conference, pp. 31-4.

Piggin, C.M. (1977). The nutritive value of *Echium plantagineum* L. and *Trifolium subterraneum* L. *Weed Research* 17, 361-5.

Popay, I. and Field, R. (1992). Grazing animals as biological control agents. Proceedings 1st International Weed Control Congress 1, 273-7.

Powles, S.B. (1987). A review of weeds in Australia resistant to herbicides. Proceedings 8th Australian Weeds Conference, pp. 109-13.

Powles, S.B. and Holtum, J.A.M. (1990). Herbicide resistant weeds in Australia. Proceedings 9th Australian Weeds Conference, pp. 185-93.

Quigley, P. (1991). The status of south-western Victorian pastures. Proceedings Grasslands Society of Victoria 32nd Annual Conference, pp. 11-8.

Smith, L.W., Martin, R. and Smith, I. (1993). The Australian national weeds strategy. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 1, 19-22.

Spain, J., Pereira, J.M. and Gauldron, R. (1985). A flexible grazing management system proposed for the advanced evaluation of associations of tropical grasses and legumes. Proceedings 15th International Grassland Congress, pp. 1153-5.

Templeton, G.E. (1987). Mycoherbicides—achievements, developments and prospects. Proceedings 8th Australian Weeds Conference, pp. 489-97.

Westoby, M., Walker, B.H. and Noy-Meir, I. (1989). Opportunistic management of rangelands not at equilibrium. *Journal of Range Management* 42, 266-74.

Wilson, I.R.B. (1993). Aboriginal and non-aboriginal recognition and awareness of noxious plants and control measures. Proceedings Proceedings 10th Australian and 14th Asia-Pacific Weeds Conference 2, 95-9.

Wolf, D.E. (1984). Changes in the science of weed control. Proceedings 7th Australian Weeds Conference 2, 86-9.

Wright, A.D. and Skilling, L. (1987). Herbicide toxicity and biological control agents. Proceedings of 8th Australian Weeds Conference, pp. 93-6.