ASSESSMENT OF THE OUTCOMES OF WEED MANAGEMENT TECHNOLOGY IN CROPPING ZONE PASTURE SYSTEMS

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Summary The paper examines changes to farming systems in the cropping zones of southern Australia. Reasons for the poor performance of self regenerating annual legume based pastures and the trend towards pastures sown for a short phase between longer sequences of crops are examined. Problems and opportunities with weed control technologies are examined for the alternative systems within which pastures now occur.

A case is made to use modelling approaches to predict the system wide implications of integrated weed management strategies. This is based on the ineffectiveness of conventional experiments approaches in providing timely information concerning the long term implication of rapidly emerging technological options.

INTRODUCTION

In the Australian agricultural context, pastures are generally a sub-system of the total farming system and producers take the whole system into account in their decision making. This is particularly true for the large areas where pastures are grown in rotation with crops. These systems will be the focus of this paper.

Powerful forces are at work shaping the nature of the farming system within which our pastures grow. Management at a farm scale is a response to these economic, technological, social and political influences. Pasture weed management technology is one component of the total technological environment which producers must consider and has an influence along with the other elements in shaping the nature of farming systems and the ways in which they are managed.

In discussing weeds of pastures in this whole farm system context, it is important to establish that weeds can be an undesirable component of either the pasture or a subsequent cropping phase or both. Weed management in pastures in this context is clearly as much about managing pasture composition for the benefit of the crop as it is for the direct benefit of livestock grazing the pasture.

PASTURE SYSTEMS – THE ROTATION CONTEXT

Traditional ley farming systems In a major review of the farming systems of southern Australia a little over a decade ago, Puckridge and French (1983) presented a view of a relatively stable farming system based around the rotation between self regenerating annual legume based pastures and cereal crops. *Trifolium subterraneum* L. (subterranean clover) and annual species of *Medicago* (medics) were seen as the driving force behind this system providing enhanced soil fertility, high pasture and crop production and a diversified income stream.

Even at this time, this 'traditional' concept of the ley farming system was recognised as an oversimplification and it was widely recognised that it was not meeting theoretical expectations under all circumstances (Carter *et al.* 1982). There was variation between states. In Western Australia and South Australia, single crops followed by one or more years of pasture were common. However, in New South Wales, it was more common to grow multiple cereal crops, sowing pasture legumes under the final crop to augment the reserves of hard seeds surviving from the previous period of pasture.

Also important were situations where the performance of available pasture legumes was poor or unreliable. This was especially the case in low rainfall areas and cereal crops were grown continuously, in rotation with volunteer pasture or following fallow.

Evolving systems Ongoing economic and technical changes have precipitated significant adjustments to farming systems. This has, in turn, modified the role played by pastures in these systems. The increases in price of wheat relative to wool has been a major factor leading to an increase in overall cropping frequency. In traditional ley systems, shortening the pasture phase commonly contributed to a reduction in pasture legume persistence and productivity. In adopting such practices, producers have been largely influenced by short term profitability factors and have been less influenced by dynamic factors such as nitrogen fixation which have their impact in a longer time frame (Pannell 1993). In some instances, producers have recognised the longer term implications of their management and have responded by increasing pasture management inputs to ensure persistence of the legume component and the productivity of the 'traditional' ley system.

Developments in herbicide technology (to be discussed in more detail later) have had a major impact on the nature of farming systems. The wider use of herbicides has allowed more effective crop weed control resulting in higher yields of crops. In addition, the wider use of non-selective herbicides as substitutes for cultivation has facilitated the development of reduced tillage systems which have overcome some of the sustainability constraints associated with increased cropping. The development of grass seed set control systems in the pasture phase has allowed improved agronomic practices such as earlier sowing. This is possible even where grass species are present for which there are no selective in crop control strategies.

A parallel technological change has been the adoption of pulses and oilseed crops into the system. Implementation of reduced tillage has allowed sequences of cereal, pulse and oil seed crops to be grown with minimal negative impact on soil structure. These sequences exhibit many of the complimentary benefits between years previously associated with pasture/cereal rotations. These include disease suppression, complimentary weed control and nitrogen fixation. However, extended sequences of crops are fundamentally incompatible with self regenerating annual pastures. Reserves of hard seeds of the annual legumes which are able to survive one or perhaps two years of cropping are depleted to the extent that self regeneration is impossible and resowing is the only means of returning to a legume dominant pasture phase. Such innovations have led to systems which follow two paths. The first is to grow crops continuously. Experience indicates that such systems are likely to be severely constrained by herbicide resistance. The second path is the adoption of a more complex rotational sequence than the 'traditional' ley system. It involves a sequence of crops, usually including a cereals, a pulse and, more recently an oilseed, grown in rotation with a pasture phase of several years (Reeves and Ewing 1993). Under these circumstances, it is necessary to reintroduce a legume at the start of each pasture phase and to recognise that any seed reserve available at the end of the pasture sequence will be of little or no value in any subsequent pasture phase.

Although the concept of phase farming is being widely discussed, its application in practice is limited. In many cases, producers have changed from a pasture/cereal rotation to continuous cropping. However, under some circumstances they have encountered sustainability constraints which prevent continuation without further modification to the system. Although fertility decline is recognised as a constraint on such systems, the development of herbicide resistance has been the most common cause of system instability and in some circumstances has precipitated a return to pastures. Pastures which result from failed continuous cropping systems fall loosely into the category of phase systems but tend to have special characteristics and management requirements compared to planned phase pasture systems.

The adoption of continuous cropping systems and phase pastures reduces the level of connection between crop and livestock enterprises especially at the paddock level. Livestock continue to be run on most cereal zone farms and the intensification of cropping has tended to emphasize the seasonal shortage of feed supply associated with the early part of the growing season. One response to this has been the allocation of paddocks with the poorest crop potential to permanent or near permanent pasture to be exploited at the time of greatest feed shortage.

The generalized rotational settings within which pastures have a role, provide a logical basis for discussion of weed management technology. However, it should be noted that the evolution of farming systems has taken place at variable rates, both between regions and between farms within a region. Some of this variation can be explained by technical parameters (differences in soil type, availability of adapted legumes, crop yields, productivity and nitrogen fixation of pastures, the potential for crop disease development). For example the adoption of pulses was rapid in Western Australia because of the early availability of *Lupinus angustifolius* L. (white lupin) which proved to be well adapted to the widespread light textured soils where the productivity of pasture was generally poor. In other regions and for other soils suitable pulse crops have only recently become available and in other circumstances no well adapted pulse is yet available. Other differences can be attributed to economic factors such as prices and production costs and at the individual farm level attitude to risk and the size of the farm debt.

KEY PASTURE WEED TECHNOLOGY ISSUES

While a large number of factors are recognise as influencing the nature and level of weed populations in pastures, it has been intervention with herbicides which has been most influential in recent system changes.

Traditional ley systems Producing high legume content pastures with the joint objectives of high nitrogen fixation, low weed seed populations and low grass borne disease is widely regarded as desirable (Carter *et al.* 1982). However, pastures have been widely observed to have declining legume content (Carter 1987). This is supported by a recent survey of pasture legume seed reserves in Western Australia which indicated that the widely sown species, subterranean clover and medics, were not abundant, especially in lower rainfall zones (Fortune *et al.* 1995). Factors such as low application of phosphate, damage by insects and diseases are often raised as key causes but the use of non-selective herbicides for seed set control (spray topping) is rarely mentioned.

There is strong evidence to suggest that spray topping should be rated a major cause of a pasture legume decline in cereal zone pastures. Observations of seed yield reduction of the pasture legume following spray topping are common (Dear and England 1987, Dowling *et al.* 1990). Where spray topping reduces legume yield it also decreases the levels of hard seed of the pasture legume (Hill 1995). This has the effect of increasing the proportion of seed lost through germination during the crop phase and reduces the quantity of seed availability to regenerate in the following pasture.

Despite these drawbacks, producers have embraced spray topping technology. In a 1993 survey of the Lake Grace district of Western Australia, a typical cereal/livestock zone, it was found that approximately 80% of the pasture paddocks to be cropped the following year were spray topped (B. Pritchard personal communication). It is clear farmers rate the short term crop benefits associated with reduced weed burden, disease levels and early sowing opportunities as more important than the reduced pasture productions and lower nitrogen fixation associated with reduced legume content.

The poor performance of traditional ley pastures in current systems provides an incentive for substitution of other rotational options, particularly pulses as the technology for these systems become established. This in turn is likely to lead to increased emphasis on phase pasture systems.

Herbicide strategies to manipulate pasture weed composition other than spray-topping are in use but all have management drawbacks. The use of simazine in winter has been shown to reduce spring dry matter production in the year of application and its use is complicated by strong seasonal effects on seed production and differences in response amongst pasture legumes (Dear *et al.* 1992).

Table 1. Spring dry matter yields (kg ha^{-1}) of the components of three subterranean clover cultivars grazed at two levels (low [L], 7.4 and high [H], 9.9 sheep ha^{-1}) and the grain yield (kg ha^{-1}) in the subsequent barley crop (from MacNish and Nicholas 1987).

Clover cultivar	Stocking rate	Pasture components (kg ha^{-1})			Barley yield (kg ha^{-1})
		Grass	Clover	Other[A]	
Seaton Park	L	230	1785	536	1930
Seaton Park	H	109	1092	619	2290
Daliak	L	324	804	96	2244
Daliak	H	633	1393	84	1848
Dinninup	L	0	3270	0	2932
Dinninup	H	0	1440	0	2675

[A] Predominantly capeweed (*Arctotheca calendula*) and a small proportion of erodium (*Erodium* spp.).

Attempts to provide tools for the selective removal of broad leaf weeds from pastures have been hampered by a lack of selectivity, seasonality of response and variation in sensitivity amongst pasture legumes species and cultivars within species (Bowran 1993, Dear *et al.* 1995, Sandral *et al.* 1995). The differential tolerance of pasture legumes to broad leaf herbicides is an indication that enhanced tolerance could be introduced through conventional breeding programs. Alternatively tolerance could be introduced using transgenetic sources of resistance.

The use of grass selective herbicides have been effective in some circumstances in increasing the legume content of pastures (Latta 1995) but their use has been restricted by their price, the tendency to shift grass populations towards grass species such as *Vulpia* which are not selectively removed (Leys 1990), and the recognition that their frequent use contributes to the development of herbicide resistance (Gill 1993).

Emphasis has been given to the need to rely less on herbicides for weed control in pastures and to place increased emphasis on management options such as grazing and mechanical topping.

An effective grazing strategy which has received little attention involves the selective removal of pasture weeds by grazing animals (generally sheep) from a pasture containing a mildly unpalatable legume. Work by MacNish and Nicholas (1987) shows that both grasses and broadleaf weeds were removed from a pasture containing the subterranean clover cultivar Dinninup while other cultivars of similar maturity contained a significant component of weeds (Table 1). The very high clover content was maintained even at a low stocking rate where pasture availability was high.

The yield of barley following pasture was negatively correlated with the grass content in the previous year with Dinninup pastures producing the highest barley yields. It is unclear whether the observed unpalatability of Dinninup is associated with its known high level of oestrogenic compounds. Field observations of livestock grazing Dinninup pastures indicate that animal growth rates are slightly lower in spring but rates during the summer dry period are higher, reflecting the higher quality of the legume dry material (D. Nicholas personal communication).

Irrespective of the cause of the unpalatability in Dinninup, these results demonstrate the potential for weed control offered by subtle levels of legume unpalatability. Differences in palatability have been noted in a number of legume species. These observations justify a concerted attempt to introduce and evaluate such traits to cereal zone pasture legume cultivars.

Phase systems The value of phase pastures is derived in part from the direct contribution to livestock enterprises and in part from benefits which are transferred to a subsequent crop phase. A substantial component of this transferred benefit lies in any delay to the expression of herbicide resistant weeds in the crop phase (Bathgate *et al.* 1993). Alternatively it may be derived from the provision of an opportunity for combating herbicide resistance once established. In practice, this is likely to involve the integration of non-selective herbicide use with grazing management, mechanical seed set control, green manuring etc.

Intensive cropping systems have evolved in circumstances where their profitability is significantly greater than systems which include a pasture phase. Extra costs or reduced returns associated with herbicide resistance can reduce the threshold of pasture productivity required for their inclusion as a component of rotations. The advent of herbicide resistance has increased the likelihood that pasture phase innovations will be adopted and justifies continuing research investment.

In seeking improved genotypes for phase pasture systems, it is important to recognise that the characteristics likely confer success will be different from those important in traditional ley systems. Adaptation to environments in which intensive cropping is practised is a prerequisite of success. Other traits which are likely to enhance pasture phase performance including weed competitiveness and maximize the transfer of benefits to future crops include:

- Ease of harvestability to allow dense establishment at low cost. This is likely to be associated with aerial seeding to allow seed collection using conventional cereal harvesting equipment rather than specialized suction harvesters as used for subterranean clover and medics.
- Low to moderate levels of hard seededness. This would ensure dense regeneration between years within the pasture phase without the unproductive transfer of large quantities of seed to the cropping phase.
- Germination regulation mechanisms which ensure survival of a proportion of the seed pool following out of season rainfall. This characteristic is important to ensure the presence of a legume population to compete with volunteer species irrespective of germinating conditions.
- Capacity to retain vegetative and reproductive activity over an extended period to allow competition with weeds while moisture remains available in spring.
- Tolerance to non-selective herbicides for use in either winter pasture composition manipulation or seed set control.
- Tolerance to selective herbicides for broad leaf weed control.
- Plasticity of growth habit to ensure competitive behaviour over a wide range of grazing intensities.
- Mild unpalatability to allow selective removal of weeds by grazing animals.

Pasture breeders and selectors have been slow to recognise the special needs for pasture legume genotypes for phase pastures. However, programs are now underway to select genotypes for a number of niches.

An example of such an initiative is the program to identify new pasture genotypes for light textured soils where intensive cropping systems involving white lupins currently dominate. Bathgate *et al.* (1993) drew attention to the possibility of including a phase pasture in systems where continuous wheat and white lupins are the most common land use. Using the MIDAS whole farm model they predicted that a pasture productivity increase in excess of 20% would be required for the most profitable rotation to include a pasture phase. Assumptions used in their model were based on the past performance of subterranean clover in this environment. This species is only moderately well adapted to the soils on which lupins are commonly grown and cultivars in use have been developed for self regenerating systems rather than phase rotations. Given this background, the challenge to produce a cultivar for this environment suited to the phase system with the appropriate productive increase appeared attainable and a selection program was commenced.

The program has identified *Ornithopus sativus* Brot. (pink or French serradella) as the most promising species and productivity improvements well in excess of the required 20% have been obtained (B. Nutt personal communication). The species has a number of the desired characteristics including ease of seed harvest, low levels of hard seed, an extended spring growth pattern and seed dormancy mechanisms which prevent major seed losses following out of growing season rainfall. Results have been sufficiently encouraging to release the first cultivar of pink serradella (Cadiz) specifically targeted at phase pasture systems. It provides a tool for the development by researchers and producers of practical integrated weed control system in phase pastures in an environment where herbicide resistant ryegrass is already common (Gill 1993).

Extension of these ideas to other soils and regions is likely to result in the proliferation of pasture legume species and cultivars in use. Closer research integration between plant breeders and weed scientists will be needed to provide producers with comprehensive and integrated weed management advise to maximize the benefits offered by the new systems.

Permanent pastures In cropping zones permanent pastures are increasingly grown in circumstances where crops are unprofitable. Constraints such as waterlogging, salinity or excessive acidity are examples of situations where permanent pastures might be considered. It such circumstances pasture production potential can also be constrained and species such as subterranean clover and annual medics are frequently poorly adapted. New legumes are being identified for particular niches (e.g. *O. compressus* L. for acidic soils, *T. michelianum* Savi and *T. resupinatum* L. for waterlogged and mildly saline situations). These developments have created a demand for herbicide tolerance studies to be extended to include these species. However, given current returns from livestock industries, management inputs such as herbicides must be low cost in order to be adopted.

INTEGRATED WEED MANAGEMENT OF THE PASTURE PHASE

Considerable emphasis has been given to the need to rely less heavily on the use of herbicides in farming systems and where herbicides are used, to integrate them more fully with other strategies for weed control. Given the multiplicity of mechanisms put forward as components of integrated weed control in pastures (timing and intensity of grazing, selective and non-selective herbicide use for composition manipulation, non-selective herbicide use for seed set control, pasture topping, green maturing, fodder conservation etc.) it is difficult to design experiments which allow an assessment of the importance of each component and strategies to optimize their impact.

A more productive approach is likely to involve the development of simulation models of pasture systems as part of rotations. Such models can be used to assemble existing information on the components of the system from a variety of sources. Once in place the models can be validated again existing information or experiments designed to allow this to occur. Figure 1 shows diagrammatically the integrated weed management elements identified in a model (WASP – Wheat and Sheep Pasture Model) for the management of annual ryegrass as an component of a wheat-pasture rotation (Trenbath and Stern 1995).

By modelling a system consisting of a typical annual grass and pasture legume (ryegrass and subterranean clover), Trenbath and Stern (1995) established a modelling framework which could be applied to a more complex and realistic set of pasture components. It should also be recognised that their model is simplified to a single rotation in an 'average' season. Their work draws attention to the range of data needed for such studies, in particular the need for detailed seed ecology studies of important weed species.

A major commitment of resources to modelling of integrated weed management systems can be justified on the grounds of its economic importance to our farming systems and the high cost and ineffectiveness of experimental approaches in projecting the ecological implications of current or prospective management. This is especially true if we are considering farming systems not yet fully operational. Past experience gives confidence that new elements of weed management and new farming systems will be continually evolving.

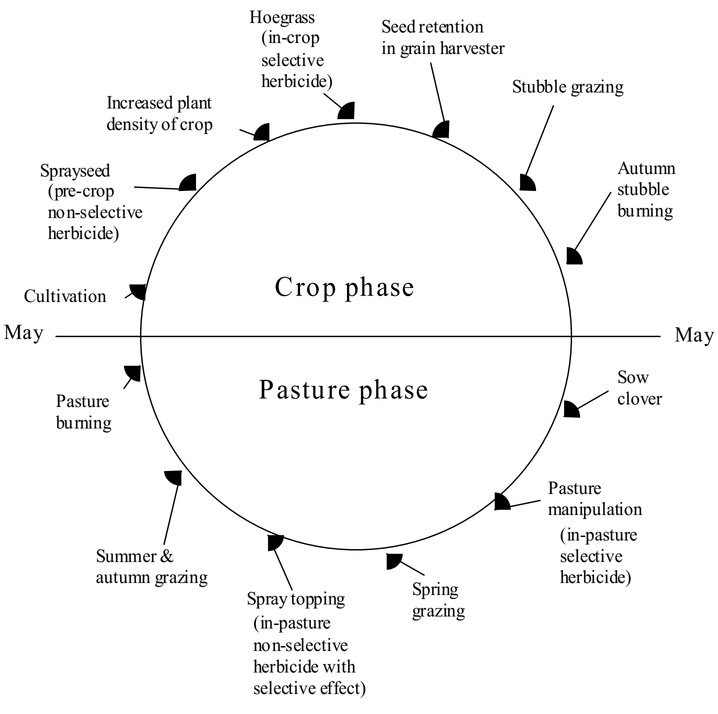

Figure 1. Options for the ryegrass in the crop and pasture phases of a wheat-pasture (WPWP) rotation (from Trenbath and Stern 1995).

CONCLUSIONS

Farming systems are undergoing rapid restructuring, principally the result of economic changes and technical innovation. In the current environment, traditional ley pastures dominated by legumes are increasingly difficult to maintain. A transition to phase pastures, more suited to intensive cropping regimes is being inhibited by the lack of well adapted pasture legume species and cultivars.

Although increased inputs of herbicides to both crops and pastures have been fundamental to recent systems developments there are indications that over use has developed. The main expression of this over reliance is the development of herbicide resistance. Its treatment or prevention is likely to shape future pasture management systems.

The rate of change in weed management systems is such that by the time medium and long term experimental evidence is available to assess system sustainability, it has already been replaced. Under these circumstances the use of models to predict system outcomes becomes increasingly important. This requires a greater commitment to collecting fundamental ecological data for key weed species and an investment in model development.

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