# Appendix 6: Journal Articles

## A6.1 Paper to be presented at the 15th Annual Australian Weeds Conference

# Insights into motivations and barriers for weed control in grazing districts of southern Australia

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**Summary** Weeds in pasture systems are a major factor reducing productivity of grazing enterprises. While a broad range of weed management products and practices have been developed, their adoption has not been widespread across the grazing industry. Weed control, like any other aspect of land management, is influenced by a complex interplay of social, economic, and biophysical factors. Social research can offer valuable insights into graziers' decisions concerning weed control, and may help to identify opportunities to improve weed management practices on grazing properties.

**Keywords** Weed control, grazing, pasture, social research, extension, decision-making, motivations, barriers.

## INTRODUCTION

The temperate perennial pasture zone of southern Australia covers an estimated 26 million hectares, and produces nearly half of southern Australia's sheep and cattle products. Pastures in this zone are typically complex mixtures of species, sown, volunteer exotic, and native plant species. Species that are considered weeds for at least part of their lifecycle will usually represent a significant part of the total biomass (Kemp *et al*. 1999).

Weeds compete directly with more desirable pasture species, lowering livestock productivity and reducing profit margins because of the costs of control (Taylor and Sindel 2000). Management practices that sustain and revive the pasture resource and provide long-term solutions to weeds have been developed (Burton and Dowling 2004). However, the conversion of research findings into change of practice on farm is a major challenge facing agricultural extension (Keeble *et al*. 2004), and this certainly appears true for weed management.

Few studies have specifically examined the processes relating to adoption of weed management strategies in grazing systems. Graziers are a diverse group of individuals, and their differences will be reflected in their perception of weeds and their approach towards adopting new weed innovations. Social research may be useful in identifying motivations, or triggers, that are likely to prompt graziers to adopt better weed management practices.

This project was commissioned by Meat and Livestock Australia, and is being carried out by staff of the Institute for Rural Futures and the School of Rural Science and Agriculture at the University of New England. The objectives of this research are to:

1. understand weed management decision-making in the southern Australian sheep and cattle grazing industries; and
2. identify motivations for, and barriers to, better weed management.

## MATERIALS AND METHODS

A literature review was completed to establish the broad scope of issues underlying weed control in grazing industries. This literature, together with discussions with weeds regulatory staff in the New England region of northern New South Wales, informed the development of a written questionnaire and a set of face-to-face interview questions.

Grazing properties were visited in the New England Tablelands and the Southern Slopes of New South Wales, and in the South East of Victoria. Face-to-face interviews were conducted with the property owner (or manager) about their approach to managing weeds. Participants were left with a mail-back survey, covering weed control methods, basic farm attributes, attitudes, information preferences and demographics. For each property visited an assessment of weed incidence and management effort was made by an accompanying weed authority officer, using a simple eight point rating system.

The data resulting from interviews and mail surveys were analysed using an extension-orientated approach. That is, the analysis distinguished between those characteristics of graziers and their properties that are not amenable to modification through extension efforts, and those that are amenable to modification. For example, the ages of graziers cannot be changed, but can be taken into account in the design of extension strategies. By contrast, knowledge may be amenable to change through extension, leading to changes in weed management practices.

In consideration of the small sample size, and since the focus of the analysis was on explanatory

relationships, a slightly relaxed threshold for statistical significance of 0.10 rather than 0.05 in analyses of variance or chi-squared tests was considered appropriate. The information resulting from this analysis has been verified through focus group, email and telephone discussion with weed regulatory and extension staff located in New South Wales, Victoria, Tasmania, South Australia, and Western Australia.

## RESULTS

**Methods of weed control** There were substantial differences in the popularity of, and familiarity with, the various methods of weed control. Boom spraying and selective use of herbicides were almost universally well regarded, while slashing and burning were not generally well regarded. Awareness of spray grazing and spray topping methods was higher among graziers with some sheep and cropping than among those with no sheep or cropping. Graziers with a higher mean proportion of their property under cropping tended to use the greatest range of approaches. Almost three-quarters of respondents did not use granular and pelletised herbicides. Producers appear to fall into four groups with respect to the mix of weed control methods they use: those using few methods, those using mainly mechanical methods, those using mainly grazing-related methods, and those using most methods (and having the lowest incidence of weeds).

**Motivations** A number of motivations for better weed control were identified. Those who gave answers relating to the health of livestock and the value of livestock products had significantly lower levels of weed infestation, as rated by the weeds officers assisting with the farm visits. Those who saw the invasive or competitive nature of plants as a problem were also more likely to have lower levels of weed infestation. Weed incidence as rated by the weeds officers assisting with the farm visits was also related to views about the usefulness of various information sources. Compared to those with higher levels of weed infestation, those with a lower incidence of weeds on their properties tended to have a higher opinion of expert producers, local councils, chemical and fertiliser company advisors and retailers and stock and station agents as useful sources of information.

**Barriers** A number of barriers were identified that are demonstrably related to poor weed control. These included the inability to identify particular grass weeds, time and monetary constraints, difficult terrain, and differences in perception of 'weeds'. There was a consistent difference in awareness of the well-known broadleaf weeds and that of grassy weeds (e.g. *Vulpia spp.*), with generally higher levels of awareness for the former group.

**Farm and farmer characteristics** Effectiveness with controlling weeds was related to farmer demography and farm characteristics, with higher levels of weed infestation occurring among older farmers with lower levels of education, who do not work off-farm, have relatively more cattle and less cropping.

**The 'three Ds'** From the face-to-face interviews and the results described above, it appeared that there are three critical factors leading to effective weed management. These are: Diligence, a Diversity of methods, and Deliberation (a planned and proactive approach to weed control). Diligence was examined using a score obtained on a series of attitude statements related to diligence. Diversity was determined on the bases of the number of weed control methods reported. Deliberation was analysed by rating weed control methods on a scale of one to three for complexity and planning. These three "Ds" define a useful three dimensional space (Figure 1) within which can be placed the styles of weed management and the effectiveness of weed control encountered in the farm visits and alluded to by key informants.

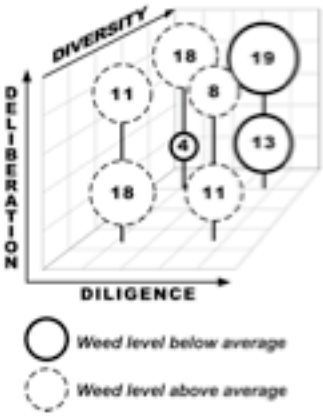


**Figure 1.** Proportions (%) of respondents in each of the eight octants defined by the median scores on each dimension.

**Sources of information** Field days, fact sheets and booklets from government departments were held in high regard by graziers as sources of weed information, particularly among better weed managers. Radio, TV and newspapers were generally less well regarded, but were more favourably viewed by the less effective weed managers. The Internet was not generally well regarded, but was perceived more favourably by those using grazing tactics and those employing a wider variety of different methods, and was used most by younger graziers.

## DISCUSSION

**Methods of weed control** Difficulties with terrain and herbicide resistance are the main problems where technological innovations may lead to improved weed control. Dislike of using chemicals may hinder weed control on some properties, suggesting more effort is required in research and extension of alternatives to herbicide application.

**Cost of weeds** Communication and extension efforts focusing on production losses should be very specific about what plants cause the losses, and make sure that graziers are able to recognise these plants in their pastures. Awareness of the costs of weeds does not necessarily lead to farmers improving their weed management. When the vaguely sensed costs of future productivity loss is weighed against the very specific and immediate costs of chemical purchase, doing nothing is an attractive option. Quantification of productivity loss in realistic farm situations is essential to influence those for whom economic considerations are uppermost in weed control decisions.

**Information sources** Information sources that are regarded as useful by the better weed managers are local in nature. Fact-sheets and booklets from government departments and field days and workshops stand out as ways of communicating information about weeds that are widely regarded as very useful. The electronic media – radio, TV and Internet – are regarded as not useful by large proportions of respondents. However, it is worth pointing out that the Internet is a rich source of information about weeds and their management, and is often used by younger graziers. It is also likely to become increasingly important in the future as older graziers retire and the younger generation take over.

**The three D's** There appear to be three critical factors that lead to effective weed management on grazing properties. Diligence is adhering to routine practices, using them in a timely fashion and treating weeds as a high priority among all the other tasks competing for the farmer's time and attention. Diversity is the number of weed control practices used, with multiple methods being used together to obtain better and more cost effective control. Deliberation is the planning of weed control, and undertaking it in a strategic fashion using knowledge of weed life cycles and knowledge of desirable (and less desirable) pasture species. These 'three Ds' provide a useful summary of opportunities and challenges for weed communication and extension strategies.

There is an identifiable group of farmers, the 'diligent', who are achieving reasonable to good weed control of declared and broadleaf weeds through diligently applying a small number of traditional approaches, such as spot spraying, boom spraying, and 'chipping them out'. These graziers compensate for 'imagination' with persistence. They are often motivated by a sense of 'pride in property' and are also concerned about the productivity of their pastures. However, they may tend to focus on declared weeds and may not be aware of certain less well-known plants that are causing production losses. They may therefore be losing income through the impact of plants that they do not recognise as 'weeds', particularly grassy weeds. With these individuals it is likely that awareness will lead to action. That is, that once these graziers are aware that a plant is reducing farm productivity, they will include it in their regular weed control operations. These graziers are not likely to respond to information on new weed control practices, since their existing methods, in combination with diligence, have so far proved effective. It is worth noting that these producers are largely reliant on application of herbicides, and that they spend a large proportion of their time and energy controlling weeds. It is likely that factors such as increased costs of herbicides, the development of herbicide resistance, reduction in availability of labour, the appearance of new weeds, and the influence of aging may reduce their ability to control weeds effectively.

Other graziers may achieve a high level of weed control though using a greater diversity of weed control methods in a more integrated fashion. This 'diverse' approach is typical of graziers in cropping systems with planned pasture rotations, where farmers are profit-driven and weeds are considered a source of lost income. The diversity of such mixed enterprises will lend itself to use of a broader range

of tools to manage weeds. Wide scale application of herbicides is routine, and herbicide resistance is the major challenge faced by this group. Another factor, particularly relevant to many younger farmers in this group, is that off-farm work reduces the amount of time they have available for controlling weeds.

**Turning effectiveness to excellence** As herbicide resistance is an issue for both the 'diligent' and the 'diverse' weed controllers, it is suggested that reduced reliance on chemical control methods is important to maintaining and improving weed control. Information on alternatives to chemical methods, and training about how to use these methods in an integrated fashion, should be a key focus for both these groups. In the case of younger graziers in cropping situations, increasing ease-of-access to information about weed control, and hence saving the amount of time and effort spent looking for it, is also likely to assist with weed control. For 'diligent' weed mangers, it is suggested weed extension efforts should raise awareness about the loss of income caused by some of the lesser-known weeds, particularly grassy weeds, as well as skills in identifying and controlling these weeds.

**Improving effectiveness of the ineffective** This study found that the least effective weed managers tend to use a few methods of control in a casual and reactive way. An adoption path for this group can, at least in theory, include any combination of increased diligence, increased diversity and increased 'deliberation'. In practice, a more planned, strategic approach to weed management will generally require the weed manager to be competent in the use of a range of weed control methods. In addition, it will require more than simple provision of information, and will probably involve educational approaches, such as have been used with Wool 4 Wealth, ProGraze and Grazing for Profit programs. This then leaves increased diligence and increased range of methods as the most effective adoption paths for the less effective weed managers. However, there is little point in adopting a wider range of control methods, unless they are applied diligently. This would suggest that improving diligence in weed control should be the primary focus for the less effective weed managers.

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## A6.2 Paper submitted to the Australian Journal of Experimental Agriculture

**Insights into motivations and barriers for weed control in temperate grazing systems of southern Australia**

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Suggested short title: Influencing weed control in southern Australia

*Abstract.* Opportunities and challenges important to effective weed management in southern grazing systems were explored using personal interviews and mail survey of livestock producers in New South Wales and Victoria. Ninety grazing properties were visited and rated for weed incidence and management effort. One hundred and twenty-two graziers were interviewed, and ninety-four completed questionnaires returned. Respondents were grouped into three categories based on farmer demographics and farm characteristics. These groups varied significantly in the range of control methods used, weed management effort, difficulties encountered with weed control, and attitudes towards weed control. Respondents were also grouped into four groups with respect to weed control methods: minimal control, mechanical control, grazing control, and maximal control. Control groups differed significantly in terms of the number and complexity of methods used, difficulties encountered with weed control, levels of weed awareness, and the value placed on various sources of information about weed control. In comparison with less effective weed controllers, more effective weed controllers had higher awareness of grass weeds, were conscious of the invasive or competitive nature of weeds, considered weed control a high priority, and were open to new control methods. Managers of properties with lower weed incidence placed a high value on information and used a wide range of information sources. Three factors were identified as critical to effective weed management: Diligence, Diversity and Deliberation. The opportunities and challenges for weed extension can be analysed in the context of these three factors.

## Introduction

Pasture weeds impose considerable annual costs on Australian livestock producers and the livestock industries. Costs to livestock production include contamination of livestock products, livestock injury and poisoning, and competition with newly sown and regenerating pastures, thereby lowering the carrying capacity of land and resulting in production losses (Campbell 1997). Sinden *et al.* (2004) estimated that the Livestock Industries spend between $315 and $345 million on control of weeds while suffering production losses of $1,870 million. In contrast, the Cropping Industries spend between $1,033 and $1,121 million on control while suffering losses of $346 million. The disparity between production losses and control costs in beef-sheep industry, which stands out in stark contrast to the grain industry, prompts the question: why aren't livestock producers doing more about weed control?

Pasture weeds are a major problem in temperate pasture systems in southern Australia. Surveys of pastures in this zone have shown that naturalised pastures are less productive than they were, while sown pastures fail to maintain their initial levels of production. Important perennial grasses have decreased in abundance, while the incidence of weeds, and annual grasses in particular, is higher relative to earlier periods (Kemp and Dowling 1991; Kemp and Dowling 2000). Weed invasion has been identified as a major factor in pasture decline, and livestock producers perceive weeds to be a major problem reducing pasture quality and persistence (Reeve and Lees 1994).

The use of herbicides and regular resowing of pastures has been effective in controlling weeds in the past. Their use is now restricted by the emergence of herbicide resistance, and growing realisation of the unfavourable economic, environmental, and human health issues associated with these practices. The current emphasis of pasture weed management is on the integration of a range of weed management methods (Dowling *et al.* 2000). Management practices that sustain and revive the pasture resource and provide long-term solutions to weeds have been developed (Burton and Dowling 2004). However, adoption of these management practices has not been widespread across the livestock industry, with the result that success with weed control is relatively limited.

Numerous studies have examined the processes relating to adoption of agricultural innovations. Adoption is not a simple matter of developing and then promoting an innovation, expecting awareness to result in implementation. Rather, adoption is primarily a process of dynamic learning and refinement of decision making over time. There is a technical basis for adoption, whereby the qualities of an innovation will itself influence its rate of adoption (Pannell and Zilberman 2000). There is also a social basis for farmers' decision making about farm innovation or change (Pannell and Marsh 1998). Farmers vary in innumerable ways, including: wealth, type and size of enterprise, age, stage of life, propensity to adopt new ideas, chemical preferences (e.g. organic farmers), attitudes towards risk and approaches to learning (Vanclay 2004).

Studies of factors influencing adoption of weed control practices in cropping systems have been conducted (Llewellyn *et al.* 2005). Comparatively few studies have examined adoption of weed control strategies in pasture systems, and fewer still have explored graziers' perceptions of the value of weed control methods or attitudes towards

weed control generally. Sindel (1996) surveyed graziers in northern NSW to investigate graziers' attitudes towards weed control. Respondents mentioned lack of time and heavy financial costs as factors in worsening weed situations. Such limiting factors were particularly significant where farms were left unattended for long periods, or were managed by older farmers.

Surveys identifying major factors influencing graziers' decisions with relation to weed control are likely to be valuable in identifying opportunities for better-targeted extension strategies. It is possible that investment directed towards such strategies will have the greatest influence on weed management practices in livestock grazing systems.

This paper reports the results from the first stage of a project commissioned by Meat and Livestock Australia to improve the understanding of the influences on the level of weed control on grazing properties, and so assist in identifying incentives and barriers to weed control and opportunities for better-targeted pasture weed extension. The first stage of the project, as described in this paper, involved face-to-face interviews and mail survey of sheep and beef graziers in temperate pasture regions of New South Wales and Victoria. The results of this stage inform the next stage of the project, which is currently in progress. This next stage involves a telephone survey of graziers across high rainfall zones of southern Australia. The combined results of both stages will inform the development of extension strategies (and associated evaluation mechanisms) to promote best weed management to producers in temperate pasture systems in southern Australia.

## Methods

### *Survey of livestock producers*

The data for this study were derived from personal interviews and a fully specified written questionnaire of livestock producers in temperate pasture systems (average annual rainfall >500 mm) of New South Wales and Victoria. A literature review, together with discussions with weeds regulatory and extension staff, informed the development of these survey tools. A total of 122 interviews was conducted in northern (31) and southern New South Wales (58) and in south-east Victoria (33). Properties in northern NSW were largely livestock orientated, with some sown (improved) pasture but little cropping. The same was true for the properties surveyed in south-east Victoria, although properties in this region were not as steep and had larger areas of sown pasture. Southern

NSW, by comparison, was flatter and many enterprises were mixed livestock and cropping, and livestock were mostly grazed on sown pasture and fodder crops. The majority of interviews (88) were conducted on the property of the participating livestock producer. In NSW another 34 interviews were conducted off-farm with livestock producers participating in the Lockhart Drum Muster (31) and a small number (3) that took place at a location specified by the interviewee, usually at local government offices.

In recognition of the strong need for professional intermediaries between extension and science (Coutts *et al.* 2001), every attempt was made to establish strong links between project staff and weeds extension providers. Property owners were first contacted by the local noxious weeds officer, to arrange permission for the researcher to accompany them onto the participant's property, and to arrange a suitable time for an interview to occur. An advantage of this approach was a personal introduction to landholders by a locally known and trusted individual. This was important in gaining access to landholders who would not normally respond to less personal mail and telephone survey, so reducing non-response bias (Armstrong and Overton 1977). Another advantage was that, for each property visited, weed incidence and weed management effort was rated on an eight-point scale, aided by the weed officers' local weed expertise and knowledge of management history. These ratings assisted in profiling graziers with respect to their effectiveness in controlling weeds.

The interviews were conducted with primary weed managers (i.e. individuals with primary or shared responsibility for weed control decisions). Participants were asked to name plants locally problematic to grazing, and describe the reasons why these plants were a problem. Interviewees were also asked what they considered important when choosing methods of weed control, and what they regarded as the key element in a good weed control program. At the end of each interview, participants were given a written questionnaire to be completed in their own time and then returned by mail. The mail questionnaire gathered data on: weed awareness, views about how much weeds were reducing returns, use and opinions of various weed control strategies, difficulties encountered with weed control, farmer demographics and farm characteristics, attitudes towards weed control, and perceptions of the usefulness of various sources for information relating to grazing weeds.

*Techniques used in statistical analysis*

Data resulting from interviews and mail questionnaires were analysed using SPSS (SPSS Inc 2001) and R (R Development Core Team 2004). Categorising farmers into groups, or 'market segments' (Barr and Cary 2000), is helpful in refining communications and targeting of extension programs, and for assessing the effectiveness of policies and programs designed for the industry overall (Angus Reid Group (ARG) 1998). Respondents were assigned to groups with respect to demographic, farm and attitudinal characteristics, and methods of weed control. The grouping technique used was cluster analysis (partitioning around mediods). Where necessary, factor analysis (principal components analysis) was used for dimensional reduction. The differences among groups with respect to other information obtained in the mail-back survey were examined using several techniques appropriate to the small sample and uneven group sizes. For continuous variables, the hypothesis of equality of means across the groups was tested using analysis of variance. Due to the unequal group sizes, Welch's variance-weighted analysis of variance was used. Equality of variance was tested with Levene's test and where this indicated a departure from equality of variance significant at the 0.05 level, Dunnett's T3 statistic was used to test equality of means in post-hoc pairwise comparisons. Where Levene's test was not significant, Tukey's Honestly Significant Difference was used for post-hoc pairwise comparisons (Hochberg and Tamhane 1987; Klockars and Sax 1986). For nominal or ordinal variables, the hypothesis of independence of factors was tested with the chi-squared statistic. When the proportion of cells in a contingency table with expected frequencies less than five was more than 20%, the p value of the chi-squared statistic was obtained by Monte Carlo simulation with 10,000 replicates. Associations between ordinal variables were expressed in terms of Spearman's rho.

*Measuring attitudinal dimensions*

A set of attitude statements relating to various aspects of weed control was included in the mail back survey. These were used in constructing Likert scales. For each statement, respondents were asked to indicate the extent to which they agreed or disagreed with that statement (5=strongly agree, 4=mostly agree, 3=neutral or not sure, 2=mostly disagree, 1=strongly disagree). Cronbach's alpha was used to calculate the reliability of each scale (values higher than 0.5 are considered reliable for a two item scale, and 0.6 for a four item scale). Factor analysis (principal

components) was used to identify attitudinal dimensions within a set of attitude statements. Attitude statements that were poorly correlated with the attitudinal dimensions were omitted from the analysis.

*Measuring demographic and farm dimensions*

Demographic and farm physical characteristics may constrain decisions relating to weed control. Such constraints will need to be considered in the development of extension strategies. To provide an overview of the nature of the variation in demographic and farm characteristics, factor analysis was again used to identify demographic and farm dimensions. The respondent scores on the resulting dimensions were analysed using cluster analysis (partitioning around mediods) to identify groups of farmers sharing similar demographic and farm characteristics.

*Methods of weed control*

Monothetic divisive clustering (a method appropriate for binary data) was used to divide respondents into weed control groups according to methods of weed control they used. The various weed control methods were rated on a scale of 1 to 3 (where 1 is relatively simple, 3 is a complex method requiring specific skills, and 2 is intermediate between the two extremes). This system enabled a weed control complexity rating to be calculated for each respondent.

*Measuring weed awareness*

The mail-back survey contained a list of 17 to 18 weeds for each region, a total of 30 different weeds across the three regions. Producers were asked for each weed in the list: whether it was present in the district, whether it was regarded as a weed, and how easy or difficult it was to identify. Using a scoring system based on proportion of correct answers, it was possible to calculate weed awareness scores for respondents across weeds in their region. It was also possible to obtain awareness scores for individual weeds, calculated across all respondents in a region. For some of the weeds listed in the survey it was not possible to unambiguously assign answers as correct or incorrect. These weeds were excluded in developing awareness scores.

*Perceptions and attitudes*

Relationships were explored between weed awareness and attitudes on the one hand, and, on the other, demographic and farm characteristics,

weed incidence, weed management effort, weed control, and views about the usefulness of farmer and industry newsletters as means of communicating information about weeds. A variety of statistical tools were used to test these relationships, including ANOVA, Spearman's rho, and the chi squared test.

*Identifying extension groups*

Respondents were divided into groups according to whether their score on each of three dimensions was above or below the median. These dimensions were: diligence, measured using scores on attitude statements, diversity, measured by the number of weed control methods respondents considered worth doing in their situation, and deliberation, measured using the complexity of methods used by respondents.

## Results

For economy of presentation, only significant relationships ($P<0.05$) have been presented.

*Factors in effective weed management*

Interview data showed that producers who were concerned with controlling invasive or competitive weeds had significantly lower levels of weed infestation ($p=0.002$), than those who did not mention this concern. Weed incidence was also significantly lower ($p=0.045$) on properties where respondents were encountering herbicide resistance than on properties where this was not a problem. Consistent with this was a significantly higher rating for weed management effort ($p=0.045$) on properties where herbicide resistance was an issue.

Correlation patterns (Table 1) between weed awareness measures for individual weeds and weed incidence suggested that respondents with serious infestations of easily recognized weeds (e.g. blackberry, *Rubus* spp.) were more aware of these weeds. The reverse was true for less well-known weeds, such as *Vulpia*. Managers of pProperties with high infestations of common broad-leaved weeds were not aware of lesser known species, such as *Vulpia*. Examples of these correlation patterns are shown in Table 1.

*Table 1. Correlation between the weed awareness score for* Rubus *spp. and* Vulpia *spp. and weed incidence.*

| Weed | Correlation with weed incidence |
|---|---|
| *Rubus* spp. (blackberry) | +0.265** |
| *Vulpia* spp. (silver grass) | -0.266* |
| *Spearman's rho:*<br>* *denotes a significant correlation at P<0.05;*<br>** *denotes a significant correlation at P<0.01* | |

There was a significant relationship between lower weed incidence and two of the attitude statements. Respondents who placed a very high priority on weed control amongst other farm tasks had significantly lower weed incidence (p=0.045). Incidence was also lower on properties of respondents who were favourably inclined to trialing new methods (p=0.040). Weed incidence was also lower on properties where the owners placed a high value on local sources of information about weeds, such as locally well-regarded producers (p=0.006), local council (p=0.047), chemical or fertilizer company advisors (p=0.019), and retailers and stock and station agents (p=0.002). It is worth noting that effective weed controllers valued a wide range of information sources, particularly those that were local in nature.

*Demographic and farm dimensions*

Principal components analysis identified two dimensions that captured 54% of the variation among the demographic and farm characteristic variables. There was a demographic dimension (related to age, experience, working off-farm and level of tertiary education), and a farm dimension (related to farm size and type of enterprise). Within the demographic dimension, lower levels of education were associated with increased age and experience, and fewer partners working off-farm. Within the farm dimension, farm size, sheep as a proportion of total livestock and area cropped tended to be positively correlated. The two dimensions were not fully independent, with mean level of education increasing with the amount of cropping, with sheep as a proportion of total livestock, and with the size of the property.

Cluster analysis on the respondents' scores on these two dimensions showed there was some grouping of respondents, best represented by a three cluster solution. Group 1 was dominated by farmers from southern NSW, and were younger, less experienced farmers with higher levels of

education and higher incidence of off-farm work. Respondents in Group 2 were older, more experienced farmers, with lower levels of education, and less involvement in off-farm work. There were approximately equal proportions of Group 2 farmers in each of the three zones. Group 3 was the smallest, and consisted of older more experienced farmers with lower levels of education and less incidence of off-farm work. Farmers in this group differed from Group 2 farmers in that they were mostly from smaller cattle properties in northern NSW and south-eastern Victoria.

These groups differed significantly in the level of weed management effort (p=0.028), with Group 1 expending the most effort (7.26), followed by Group 3 (6.72) and lastly by Group 2 (6.46). These groups also varied significantly in the range of control methods used, difficulties encountered with weed control, and attitudes towards weed control.

As an example, the groups varied significantly in the pattern of opinions about spray topping (or winter cleaning). Almost 70% of Group 3 members were not familiar with spray topping. It was well regarded by 60% of respondents in Groups 1 and 2, although these groups differed in proportions of those who did not believe it was worth doing, with 26% in Group 1 compared with 5% in Group 2. Spray grazing showed a similar but less pronounced pattern of opinion across the three groups.

The three groups differed significantly with respect to three weed control difficulties (factors limiting effective weed control). These were lack of money, difficult country, and weed spread from neighbours. Lack of money was given by all respondents in Group 3, compared with 61% in Group 1 and 48% in Group 2 (p=0.049). Difficult country was given by 67% of respondents in Group 2, compared with 30% of respondents in Groups 1 and 3 (p=0.035). The problem of weeds spreading from neighbours was identified by all Group 3 respondents, compared with 37% in Groups 1 and 2 (p=0.008).

Chi-squared tests revealed that the 3 groups varied significantly ($c^2$=0.004) in their views about consulting with others about weed problems. Group 1 felt strongly that it was important to consult others (70%). Groups 2 and 3 reacted in the opposite way, with 81% of Group 2, and 57% of Group 3 not regarding consultation with others to be important. The groups also varied significantly ($c^2$=0.019) in their views about the benefits of new weed control methods compared with the cost of trialing. Trialing was preferred by older farmers, with 43% of Group 2 and 71.4% of Group 3 agreeing it was worthwhile to trial new methods. A smaller proportion of Group 1 (17.4%) were favourably disposed to trialing new methods.

*Weed control groups*

Monothetic divisive cluster analysis was used to divide respondents into four groups using their responses on whether or not they were spray grazing, slashing or using quarantine measures. The four groups were: neither spray grazing nor slashing (29% of respondents), not spray grazing but slashing (15%), spray grazing but not using quarantine measures (26%), and using both spray grazing and quarantine practices (30%). After examining their patterns of use of all weed control methods listed in the questionnaire, these were referred to as the minimal, mechanical, grazing, and maximal control groups respectively. The four groups were not evenly distributed across the three regions surveyed. The minimal and mechanical control group were most strongly represented in northern NSW, while the grazing and maximal control groups have greater proportions in southern NSW. The mean proportion of property area under cropping was much higher for the grazing and maximal control groups (15% and 20% respectively) than for the minimal and mechanical control groups (1% and 3% respectively). There was a significant difference ($p<0.0005$) between the number of weed control methods used within each group. This number was highest for the maximum control group with a mean of 10.2, followed by the grazing control group (7.2), the mechanical group (7.1) and the minimal control group (4.9). Those with cropping enterprises used the greatest number of weed control strategies. They were also significantly different with respect to the mean control complexity rating, although in this case the grazing control group was highest with a mean complexity rating of 1.7, then the maximal control group (1.6), the mechanical control group (1.4) and the minimal control group (1.4).

For two of the difficulties encountered with weed control, there were two significant differences between the weed control groups: herbicide resistance ($p=0.019$) and dislike of using chemicals ($p=0.002$). In the maximal control group, 41.7% of respondents ticked herbicide resistance, compared with 15.4% in the mechanical control group, 12% in the minimal control group, and 9.1% in the grazing control group. Dislike of using chemicals was nominated by 36% in the minimal control group, compared with 7.7%, 0% and 8.3% in the mechanical, grazing, and maximal control groups respectively.

The weed control groups were significantly different in terms of weed awareness measures for easily recognised broadleaved weeds reflecting, at least in part, the geographic distribution of the weed control groups and

the weeds. The minimal group had the highest score, and the maximal group the lowest score. Some examples are shown in Table 2.

*Table 2. Differences across the weed control groups in weed awareness measures.*

| **Weed Control Group** | **Mean weed awareness score** | |
|---|---|---|
| | **Blackberry** | **Sweet briar** |
| Minimal control | 0.942 | 0.696 |
| Mechanical control | 0.667 | 0.456 |
| Grazing control | 0.725 | 0.652 |
| Maximal control | 0.569 | 0.306 |
| *blackberry: Anova, p=0.025, sweet briar: Anova, p=0.022* | | |

The four groups differed significantly in their rating of usefulness of expert producers as a source of information about weeds ($c^2$ test p=0.042). The maximal control group rated them the most highly, with 61.5% of respondents considering them very useful, 34.6% some use, and 3.8% no use. The other significant difference was the perceived value of the Internet ($c^2$ test, p=0.015). The maximal group again rated it the most highly, with 21.1% of respondents considering it very useful, 63.2% some use, and 15.8 not useful, compared with the minimal control group, proportions of which were 0%, 22.2% and 77.8% respectively.

*Critical success factors*

From the analysis of the interviews and mail back questionnaire, three critical factors were identified as important to effective weed management. We refer to these as the three "D's": Diligence, Diversity, and Deliberation. *Diligence* is adhering to routine practices, using them in a timely fashion and maintaining weed control as a high priority among all the other tasks competing for the farmer's time and attention. *Diversity* is the number of weed control practices used, and how multiple methods are used together to obtain better and more cost effective control. *Deliberation* is the planning of weed control, and undertaking it in a strategic fashion that takes advantage of knowledge of the life cycles of weeds and desirable pasture species. As these factors did not become evident until after the interviews and mail survey were carried out, there

were no variables available to the analysis specifically designed to gauge respondents' situation relative to these factors. However, it was possible to derive three proxy variables representing the factors using the questions available in the mail back survey. Diligence was approximated with the mean score on a group of attitude statements. Diversity was approximated by the number of weed control methods the respondent considered well worth doing. Deliberation was approximated with the complexity of practices used.

Respondents were divided into eight groups according to whether their score on each of the three proxy variables was above or below the median. These groups can be plotted in the three dimensional space defined by the three factors (Figure 1, Table 3).

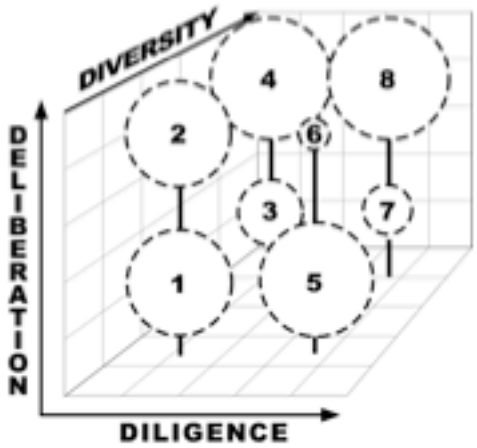


*Figure 1. Distribution of respondents across the eight octants defined by the median scores on each dimension of diversity, deliberation and diligence. Size of circle is proportional to the number of respondents in each group.*

*Table 3. Proportion of respondents falling in each of the eight groups defined by the median scores on each of the three dimensions.*

| | Prop'n of respondents in group (%) | Position of mean score on dimension relative to median | | | Mean score | |
|---|---|---|---|---|---|---|
| | | Diligence | Diversity | Deliberation | Weed incidence | Effort |
| Group 1 | 15.1 | below | below | below | 2.3 | 3.1 |
| Group 2 | 15.1 | below | below | above | 2.2(1) | 2.7(3) |
| Group 3 | 9.3 | below | above | below | 1.1(1,2) | 3.8(2) |
| Group 4 | 17.4 | below | above | above | 2.2 | 3.1 |
| Group 5 | 16.3 | above | below | below | 2.1(2) | 3.2 |
| Group 6 | 2.3 | above | below | above | 1.5 | 3.8 |
| Group 7 | 7.0 | above | above | below | 1.8 | 3.3 |
| Group 8 | 17.4 | above | above | above | 1.6 | 3.6 |
| Total | 100 | | | | | |
| Average for all groups | | | | | 1.5 | 3.2 |
| Test significance | | | | | Anova, p=0.012 | Anova, p=0.014 |
| N | | 86 | 86 | 86 | 79 | 79 |

**The numbers in brackets identify pairs of mean values with post-hoc pairwise comparisons significant at the 0.05 level (e.g. Groups 2 and 3 differ significantly from each other in terms of weed incidence (Group 2 = 2.2, Group 3 = 1.1) and in terms of weed management effort (Group 2 = 2.7, Group 3 = 3.8).*

***The sample size in the right most two columns is lower than that in the other columns, due to ratings by weeds authority staff not being available for a small number of properties.*

Using information on mean weed incidence and management effort ratings provided by weeds authority staff accompanying the farm visits (Table 3), some general trends can be observed in the way group members are positioned in Figure 1. Less effective weed managers (i.e. those with higher weed incidence and lower management effort) tend to be positioned in the bottom, left, and front of Figure 1. These are those who place a low priority on weed control, using a few methods in an unplanned and reactive way. The top, rear of Figure 1 is where better weed managers are located – those who diligently use a wide range of weed control methods in a planned, strategic way. The obvious exceptions to these generalizations are Groups 3 and 4. As evidenced by these exceptions, weed levels do not necessarily decline in a simple linear fashion from the bottom, left, front of Figure 1 to the top, right, and rear. Group 6, for example, achieve reasonably high levels of weed control (weed incidence = 1.5) using relatively few methods.

The eight groups varied significantly with respect to the mean proportion of property area under crops (Anova $p<0.0005$), and to proportion experiencing herbicide resistance (Anova $p=0.020$). Groups 3

(36.9%), 8 (20.6%) and 4 (16.4%) had the highest mean proportion of property under crops. These groups were also those with the highest proportion of members encountering herbicide resistance, with Group 3 having the highest proportion of respondents encountering resistance (62.5%), then Group 8 (33.3%), and finally Group 4 (20%). The eight groups also differed significantly in the proportion of respondents that rated two information sources as very useful: daily and local newspapers ($c^2$, p=0.021) and the Internet (chi-squared, p=0.029). Newspapers were most valued by Groups 5 (50%) and 3 (25%), while Groups 7 and 8 were equal (33.3%) in the proportion of respondents rating the Internet as very useful.

**Discussion**

The three "Ds" define a useful three dimensional space (Figure 1) within which can be placed the styles of weed management and the effectiveness of weed control encountered in the farm visits and alluded to by key informants. Improvements in weed management will involve moving along an adoption path from one point in the space depicted in Figure 1 to another point. Adoption paths involve different sets of barriers and motivations, depending on where they are located and who is travelling the path. Adoption paths will also have differing communication and extension requirements. The preceding analysis provided a description of how various barriers and motivations were related to weed incidence and management effort. It also identified aspects that are not open to change through extension, such as rugged terrain, but are fixed realities of the heterogeneous farming sector which extension has to accommodate. The discussion now turns to the possible adoption paths which might be encouraged, and some of the main motivations and barriers associated with them.

Lack of finances available for weed control is a limiting factor in weed control. It should be first noted that there are situations in which it is not economically feasible, in terms of private costs and benefits, to overcome weed problems that have got out of hand. Such may be the case on smaller beef properties in the high rainfall zone, where producers have not been able to make the productivity gains necessary to maintain their real incomes (ABARE 2004). There may be pubic benefits to weed control in these situations, which then provide a policy rationale for public investment in weed control on private property. The policy approach will obviously be very different for properties where weed control is only rational on public good grounds, compared to properties

where weed control is economically feasible in terms of private costs and benefits. The motivations for, and barriers to, participation by landholders in public good weed control programs lay outside the scope of this project.

In the case of weed control for private benefit, an adoption path for the less effective weed managers can include, at least in theory, any combination of increased diligence, increased range of methods (diversity) and increased planning (deliberation). In practice, a more deliberative approach to weed management will generally require the strategic integration of a range of weed control methods. To be successful, such an approach requires that the user is competent in the use of a diverse range of methods. Being able to use a diverse range of methods in a strategic, integrated fashion, is complex and involves high learning requirements. Complexity and high additional learning requirements have been identified as factors likely to constrain adoption (Bullen and Woods 1999; Frank and Chamala 1992; Vanclay 1992), and may therefore limit movement along the deliberation and diversity dimensions. This would suggest that improving diligence using a few methods of weed control should be the primary focus for the less effective weed managers. This project has so far identified a number of reasons contributing to lack of diligence in controlling weeds.

Firstly, weeds are defined by people's perceptions of their desirability. Noxious or declared weeds carry a financial penalty for failure to control, and are therefore obviously undesirable. Such is the case with well-known broadleaf weeds, such as blackberry. Nonetheless, it appears likely that there is a significant number of graziers with higher than desirable levels of infestation of well-known broadleaf weeds, such as blackberry. As awareness of these weeds is typically high in these situations, further awareness raising activities are likely to have limited impact. Increased fines for failure to control may be one option to motivate action, though there are inherent disadvantages of the regulatory approach.

The situation is more complex with plants that, although reducing productivity, are not declared weeds. This is especially true for grass weeds, such as *Vulpia* spp. It appears that there is little recognition of these plants as 'weeds', except where their competitive and invasive nature is recognised. Raising awareness about the economic costs of less well-known grass weeds may increase the effort spent controlling these weeds. Economic evaluations of pasture weeds will, however, be hampered by the complexity of plant-animal relationships, and by the lack

of consensus on the 'weediness' of certain plants, particularly those with seasonal grazing value (Vere *et al.* 2002). Communication and extension efforts focusing on production losses should be very specific about what plants cause the losses, and make sure that graziers are able to recognise these plants in their pastures.

The low priority status of weed control among other farm tasks is another factor reducing diligence. Efforts are focused towards tasks that are perceived as being more urgent, such as feeding stock or controlling internal parasites. Economic evaluations of the impacts of these weeds on productivity are likely to raise the priority placed on weed control. Awareness of the costs of weeds may not necessarily lead to farmers improving their weed management. When the vaguely sensed costs of future productivity loss are weighed against the very specific and immediate costs of chemical purchase, doing nothing is an attractive option. Quantification of productivity loss in realistic farm situations is essential to influence those for whom economic considerations are uppermost in weed control decisions. However, there are those graziers who are not interested in improving profitability. For example, older farmers approaching retirement are unlikely to risk learning and applying new production practices, especially if there are additional costs involved (Drost *et al.* 1996). Farmers approaching retirement may place more priority on weed control if they were made aware of the reduction in the sale value of their property due to the presence of weeds.

A proportion of graziers will often achieve a reasonable level of weed control through diligent use of a limited number of more traditional approaches, such as spot spraying, boom spraying, and 'chipping them out'. These graziers compensate for 'imagination' with persistence, placing a high priority on weed control. However, there is a tendency to focus on declared weeds, and they may not be aware of plants that are causing production losses on their property, particularly grass weeds. With these individuals it is likely that once these graziers are aware that a plant is reducing farm productivity, they will include it in their regular weed control operations. Since the methods used by these graziers, in combination with diligence, have so far proved effective, they see little need for adopting new methods of weed control. The effectiveness of their preferred methods is reduced in difficult country, where access is restricted by rugged terrain or dense vegetation, and control methods are limited to the costly aerial application of herbicides and biological control, where that is available. Persistent spot and boom spraying with herbicides has the potential for herbicide resistance to develop. Strategies

to prevent the development of resistance, and methods suited to controlling weeds in rugged country at low cost, are likely to capture the interest of these graziers, and may provide useful 'angles' for weed extension activities. Further, as these graziers place a high value on trialing as a means of establishing the credibility of new practices, extension activities should, where possible, encourage small-scale trialing of new techniques. These graziers tend to prefer local sources of information about weeds, such as fact sheets from local council and chemical companies. They are often older and do not regard the Internet as being very useful. The Internet is not recommended as a means of communicating information to this group.

Other graziers may achieve a high level of weed control though using a greater diversity of weed control methods in a more integrated fashion. Such diversity of approach is typical of graziers in cropping systems with planned pasture rotations, where farmers are profit-driven and weeds are well-recognized as a source of lost income. The diversity of such mixed enterprises will lend itself to diversity in approaches to weed management, and as the topography of these properties is typically relatively flat, the manager is less constrained in their choice of weed control methods. Application of herbicides to reduce the incidence of weeds is routine, and herbicide resistance is a factor reducing effectiveness in weed control. To be successful in improving the ability of these producers to control weeds, extension strategies should go beyond the routine application of herbicide to include a range of weed control strategies, including non-chemical methods (Pannell 2002). These producers typically place a high value on information, and particularly value consultation with local agricultural advisors. These communication strategies are recommended for extending weed information to this group.

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