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Grain grower perceptions and use of integrated weed management

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Abstract. Greater adoption of integrated weed management, to reduce herbicide reliance, is an objective of many research and extension programmes. In Australian grain-growing regions, integrated weed management is particularly important for the management of herbicide resistance in weeds. In this study, survey data from personal interviews with 132 Western Australian grain growers are used to characterise the use and perceptions of integrated weed management practices. The main objective was to identify opportunities for improved weed management decision making, through targeted research and extension. The extent to which integrated weed management practices are used on individual farms was measured. Perceptions of the efficacy and reliability of various weed management practices were elicited for control of annual ryegrass (*Lolium rigidum* Gaud.), along with perceptions of the economic value of integrated weed management practices relative to selective herbicides. All growers were shown to be using several integrated weed management practices, although the use of some practices was strongly associated with the presence of a herbicide-resistant weed population. In general, both users and non-users were found to have high levels of awareness of integrated weed management practices and their weed control efficacy. Herbicide-based practices were perceived to be the most cost-effective. Opportunities for greater adoption of integrated weed management practices, to conserve the existing herbicide resource, exist where practices can be shown to offer greater shorter-term economic value, not necessarily just in terms of weed control, but to the broader farming system.

Introduction

Since the rapid and widespread adoption of herbicides as the predominant weed management tool, weed scientists and agronomists have stressed the need for adoption of integrated weed management (IWM) in cropping systems (Buhler *et al*. 2000; Swanton and Weise 1991). This has often been related to the management and minimisation of herbicide resistance (Gill 1997; Moss 1997; Powles and Matthews 1991). The adoption of IWM has become particularly important in Australia, where existing and potential herbicide resistance in weeds is a major management challenge throughout grain-producing regions (Llewellyn and Powles 2001; Nietschke *et al*. 1996; Pratley *et al*. 1993; Walsh *et al*. 2001).

Responses to herbicide resistance take 2 main forms: pre-emptive and reactive. Management strategies that are primarily intended to delay or prevent future herbicide resistance development can be described as pre-emptive. These have also been described as anti-resistance strategies (Orson 1999). Reactive management controls weed populations that have developed resistance to previously effective herbicides. Weed scientists and extension agents have often emphasised the need for greater pre-emptive adoption of IWM, to prevent or delay the development of herbicide resistance, arguing that the current level of adoption is suboptimal (Gill 1997; Moss 1997; Powles *et al*. 1997; Roush and Powles 1996).

Several factors have been identified that are likely to act negatively upon the decision by growers to invest in adopting IWM practices to prevent or delay resistance (Llewellyn *et al*. 2001; Pannell and Zilberman 2001). These include socio-economic factors, such as the preference for returns in the short term over the long term, expectations of new herbicide technology, and uncertainty as to whether resistance will actually be prevented or delayed by adopting the practices. In addition, there is the range of factors that typically slow the adoption of complex innovations (see Pannell 1999). If weed management practices are clearly profitable to the farming system in the short term, the influence of these factors may be minimised.

Surveys of the use of weed control practices by Australian grain growers have been conducted (e.g. Alemseged *et al*. 2001). However, researchers have paid little attention to grower perceptions of the efficacy and economic value of IWM practices, or to the association between herbicide resistance status and the adoption of weed management practices. Grower perceptions of various attributes of a practice influence the perceived relative value of the practice

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and subsequent adoption decisions (Adesina and Baidu-Forson 1995; Wossink *et al*. 1997). Determining grower perceptions allows for the existing state of knowledge to be recognised. Through comparison with well-established scientific knowledge, it is possible to identify opportunities where targeted extension can have the greatest influence on grower decision making.

The objective of this paper is to provide insight into the IWM practices used by growers and their perceived value for weed management. Based on data from a survey of Western Australian grain growers, we examine whether growers are employing IWM in the absence of resistance and whether non-users have a sound knowledge of IWM practices. In one section, the adoption and extent of use of individual IWM practices is presented, then grower response to the presence and/or threat of herbicide resistance is characterised. In a second section, grower perceptions of practice efficacy and value are presented. Finally, we identify opportunities for extension and implications for increasing the pre-emptive adoption of IWM for resistance management.

Methods

Survey of grain growers

The data for this study were derived from a survey of 132 randomly selected grain growers from the Dalwallinu (DAL) shire (64 growers) and Katanning–Woodanilling (KAT) shires (68 growers) of Western Australia. A database of property owners, based on information held by local government, was used to initially contact growers by phone. In DAL, 72 primary cropping decision makers (i.e. individuals who were primarily responsible for decision making about cropping on the farm) were approached, resulting in 64 interviews. In KAT, 78 primary cropping decision makers were approached, resulting in 68 interviews. The personal interviews, based on a fully specified questionnaire, were conducted with primary cropping decision maker(s) during farm visits, before crop sowing in February–March 2000. Farms managed by growers in the DAL region were larger on average (3864 ha), had a greater proportion of land cropped (70%), and received a lower average annual rainfall (about 325 mm) than properties in the KAT region (1812 ha, 55%, 450 mm).

Most questions on weed management practices focused on the most important cropping weed, annual ryegrass (*Lolium rigidum*) (Alemseged *et al*. 2001), and resistance to ACCase-inhibiting and ALS-inhibiting herbicides. A field survey of weed populations has shown that these represent the most common forms of herbicide resistance in Western Australia (Llewellyn and Powles 2001). The 2 regions represent: (i) an area of the Western Australian wheatbelt where herbicide resistance is well-established (DAL); and (ii) an area where cropping has more recently intensified and weed populations with serious levels of resistance are not yet widespread (KAT). Only aggregated results are presented, unless statistically significant differences between the 2 areas were found. The extent and perceptions of herbicide resistance are described in more detail in Llewellyn *et al*. (2002).

Measuring integrated weed management adoption

Although integrated pest and weed management are sometimes described as large, diverse packages of practices, it is generally recognised that farmers adopt specific techniques or small bundles of individual practices (de Buck *et al*. 2001; McDonald and Glynn 1994; Sorensen 1993; Wearing 1988). This study is based on the premise that growers adopt their own set of individual IWM practices from a larger suite of available practices. The weed management practices referred to in this study as IWM practices apply little or no selection pressure for herbicide resistance and do not involve the use of any selective herbicides. They therefore represent biological, cultural, mechanical and, to a lesser extent, non-selective herbicides (see Appendix for a description of the practices).

The ability to use some practices can be affected by seasonal conditions and crop rotation, so the use of practices over more than 1 time period was measured. Past use was measured by asking whether a practice had been used on the farm in the past 4 years. Similarly, intentions for future use included a 4-year period beginning with the cropping season in the year in which the survey was conducted (2000).

Growers were asked about their intended use of specific practices in the coming season, including their expectations of the proportion of land on which practices would be used. Logistic regression analyses predicting IWM practice use were conducted to determine the independence of resistance status and region and included a resistance status × region interaction term as an explanatory variable.

Factor analysis (Manly 1986) was used to test whether particular sets of practices tended to be used together by a farmer. By examining correlations between the use of practices, it was possible to identify the 'factors' that account for much of the variation in the data. Factor analysis has previously been applied to explore the use of integrated pest management practices (Hubbell *et al*. 1997; McDonald and Glynn 1994). Here, the aim was to identify sets of IWM practices associated by their common use on the same property.

Measuring perceptions

The perceived levels of efficacy (percentage control of annual ryegrass) and the perceived economic values of individual IWM practices were elicited from users and non-users of those practices. Perceived efficacy was calculated using triangular distributions. Respondents were asked for their perceived 'most likely', 'highest possible' and 'lowest possible' percentage of weed control that they would expect if using the practice on cropping land typical for their farm. The expected values for control and variance in control were then calculated (Hardaker *et al*. 1997).

To obtain a measure that incorporated more than just perceived efficacy, growers were asked to consider all direct and indirect costs and benefits involved in using the practices. As examples of indirect costs or benefits, time and effects on the soil were suggested for consideration. Growers were then asked to consider these issues in judging 'cost-effectiveness' and to rate the value of practices using a scale of 1–9. On this scale, 5 was 'as valuable as an effective selective herbicide', 1 was 'much less valuable' and 9 was 'much more valuable'. Due to the non-normal distribution of the response data for some practices, the rank-based Wilcoxon (Mann-Whitney) test (see Meddis 1984) was used to test for associations with resistance and region.

Results

Adoption of integrated weed management practices

Use of individual practices. The proportions of growers who have used, or intend to use, the various practices in the next 4 years are shown in Table 1. Pasture spraytopping and stubble burning were the 2 most used practices. Of the practices examined in detail in the survey, manuring and catching were the 2 least used practices; however, they were also the 2 practices predicted to experience the greatest relative increase in use over the next 4 years. Growers using catching tend to use it extensively across their property. Although only 7% of growers intended to use seed catching in 2000, those growers, on average, expected to use it on 87%

Table 1. The use of integrated weed management practices by growers

Data were not collected for some practices, during some periods (indicated by dash)

Integrated weed management practice	Proportion of growers using practice (%) Past 4 years	2000	Next 4 years	Cropped land treated (%)[A] 2000
Stubble burning	78.8	76.5	84.8	25.8
Catching	9.8	6.8	22.7	87.2
Cultivation	56.8	45.9	58.3	49.2
Autumn tickle	49.2	43.9	60.6	35.6
Delayed sowing	40.9	45.5	58.3	34.6
Double-knock	57.6	56.8	74.2	46.6
Croptopping	33.3	30.3	49.2	10.9
Manuring	13.6	16.7	32.6	7.4
Hay	47.0	38.6	50.8	3.9
Spraytopping	97.7	94.5	94.5	75.3
High wheat sowing rate[B]	24.2	56.1	61.4	52.7
Heavy grazing	61.4	—	—	—
Pasture phase (treated)	54.6	—	—	—
Barley for weed control	28.8	—	—	—
Fallow	23.5	—	—	—
Harvest low, no spread, burn	21.2	—	—	—
Swathing for weed control	13.6	—	—	—
Mechanical pasture top	7.6	—	—	—

[A]Mean percentage of 2000 cropping land growers expected to be treated using a given practice in 2000, except 'Spraytopping' which is the mean percentage of pasture treated.
[B]High if farm average >65 kg/ha. 'Past' and 'Next' use is based on 1995 and 2004 wheat sowing rates, respectively. Proportion of cropped land treated is percentage of crop land sown to wheat at high sowing rate.

of their cropping land. In contrast, hay, croptopping and manuring were expected to be used on 4, 11 and 7% of land, respectively. Spraytopping was extensively used on pasture land.

The adoption of some practices was associated with the resistance status of the farm. In regression analyses, the resistance status × region interaction term was not significantly associated with the use of any practice (data not shown). Only differences between growers with and without a herbicide resistance problem are presented here (Table 2).

As shown in Table 2, some practices were more likely to be used by growers who have developed herbicide resistance on an area of their farm. For example, the proportion of growers using croptopping was more than 3 times greater for growers with herbicide resistance than for those without it. In contrast, the proportion of growers using, or planning to use cultivation, spraytopping pasture and high sowing rates was similar for growers with and without resistance.

The use of multiple IWM practices. Over the past 4 years, growers with resistance used an average of 8.4 (median 9) of the listed practices, significantly ($P<0.001$) more than growers with no resistance (mean 6.6, median 6). The average for all growers was 7.7, with a range from 3 to 13 practices used. All growers used several practices that can be classified as IWM practices.

Factor analysis was applied to the use of practices in the previous 4 years (Table 3). The first 3 factors are discussed because each of these explains greater than 20% of the variation in the sample. The first factor has an eigenvalue greater than one, therefore it is likely that this is the only factor that explains more variance than one of the variables (practices) on its own. This first factor, explaining 70% of the variation, has heavy loadings for autumn tickle, delayed sowing, double-knock, croptopping, low harvesting with burning of windrows, and swathing lower than normal. This indicates that the use of one of these practices was often associated with use of others in this set of practices.

The second factor is associated with the use of weed control in pastures, with heavy loadings for spraytopping, pasture phases of 2 years or more, and heavy grazing. The third factor has heavy loadings for the 'traditional' cropping practices of cultivation and burning of crop residue (whole paddocks).

Perceptions of integrated weed managemnt practices

Perceptions of efficacy. The perceived percentage ryegrass control attainable was elicited for IWM practices, the pre-emergence herbicide trifluralin, and a selective post-emergence herbicide to which ryegrass shows no herbicide resistance (a hypothetical new herbicide described as being similar to diclofop in the absence of resistance). By obtaining the perceived most likely, lowest possible, and highest possible percentage control, triangular probability distributions were produced. Figures 1 and 2 show the median expectations of ryegrass control for each practice. For practices in Figure 1, ryegrass control is defined in terms of reduction in ryegrass seed production/viability. For the

Table 2. The use of integrated weed management practices by growers of crops with herbicide resistance (HR, *n* = 77) and without herbicide resistance (NoHR, *n* = 55)

Data were not collected for some practices, during some periods (indicated by dash)

Integrated weed management practice practice	Proportion of growers using practice (%) Past 4 years HR	NoHR	2000 HR	NoHR	Next 4 years HR	NoHR	Cropped land treated (%)[A] 2000 HR	NoHR
Stubble burning	87.0	67.3	84.9	65.5	94.8	70.9	24.8	27.8
Catching	13.0	5.5	10.4	1.8	31.2	10.9	85.6	100
Cultivation	55.8	58.2	49.4	49.1	53.3	65.5	37.4	57.9
Autumn tickle	62.3	30.9	57.1	25.5	71.4	45.5	35.9	34.6
Delayed sowing	46.8	32.7	53.2	34.6	67.5	45.5	26.0	53.1
Double-knock	61.0	52.7	62.3	49.1	79.2	67.3	47.6	44.8
Croptopping	46.8	14.6	44.2	10.9	64.9	27.3	10.9	10.8
Manuring	15.6	10.9	20.8	10.9	36.4	27.3	8.0	5.7
Hay	41.6	54.6	31.2	49.1	48.1	54.6	3.8	4.0
Spraytopping	97.3	98.2	94.7	94.3	96.0	92.5	81.1	67.1
High sowing rate[B]	24.7	23.6	57.1	54.5	67.5	52.7	57.0	46.3
Heavy grazing	62.3	60.0	—	—	—	—	—	—
Pasture phase (treated)	58.4	49.1	—	—	—	—	—	—
Barley for weed control	35.1	20.0	—	—	—	—	—	—
Fallow	36.4	5.5	—	—	—	—	—	—
Harvest low, no spread, burn	31.2	7.3	—	—	—	—	—	—
Swathing for weed control	16.9	9.1	—	—	—	—	—	—
Mechanical pasture top	7.8	7.3	—	—	—	—	—	—

[A]Mean percentage of 2000 cropping land growers expected to be treated using a given practice in 2000, except 'Spraytopping' which is the mean percentage of pasture treated.
[B]'Past' and 'Next' use is based on 1995 and 2004 wheat sowing rates, respectively.

practices in Figure 2, ryegrass control represents the perceived percentage reduction in ryegrass density that results in-crop due to the use of the practice, relative to the ryegrass density if the practice had not been used.

An ideal weed control practice would offer a very high probability of achieving a very high modal efficacy, that is, reliable high levels of weed control. Relative to all of the IWM practices, growers perceive that a post-emergence selective herbicide is nearest to achieving those characteristics of control (Fig. 2). The perceived high efficacy, low variance characteristics of post-emergence

Table 3. Factor analysis of integrated weed management (IWM) practice use showing loadings for three IWM use factors

Orthogonal varimax rotation was applied to aid interpretation (Manly 1986); for clarity the factor loadings for each practice are only shown if >0.20; manuring did not have a factor loading >0.20

Practice	Factor 1	Factor 2	Factor 3
Stubble burning	—	—	0.42
Catching	0.20	—	—
Cultivation	—	—	0.38
Autumn tickle	0.43	0.26	—
Delayed sowing	0.36	—	—
Double-knock	0.36	—	—
Croptopping	0.66	—	—
High sowing rate	0.23	—	—
Heavy grazing	—	0.45	—
Pasture phase (treated)	—	0.41	—
Harvest low, no spread, burn	0.53	—	—
Swathing for weed control	0.52	—	—
Eigenvalue	1.90	0.75	0.58
Proportion of variance	0.70	0.28	0.21

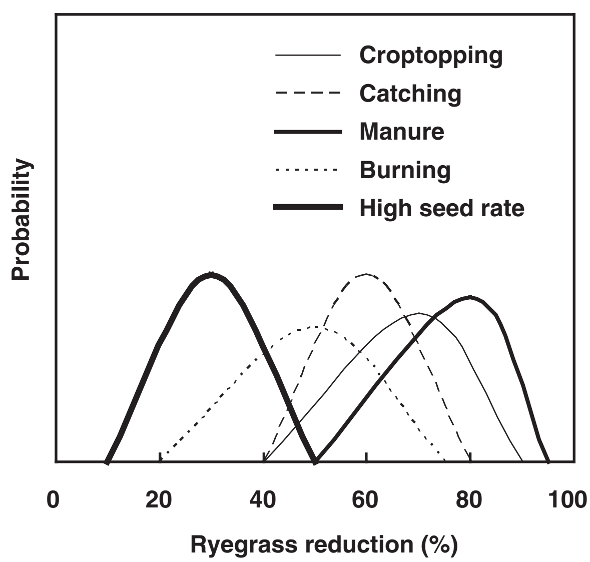

Figure 1. Subjective probability distributions for the perceived ryegrass control achieved from 5 weed control practices. Triangular distributions drawn using the median of the most likely percentage control, the lowest possible and highest possible percentage control values elicited from growers.

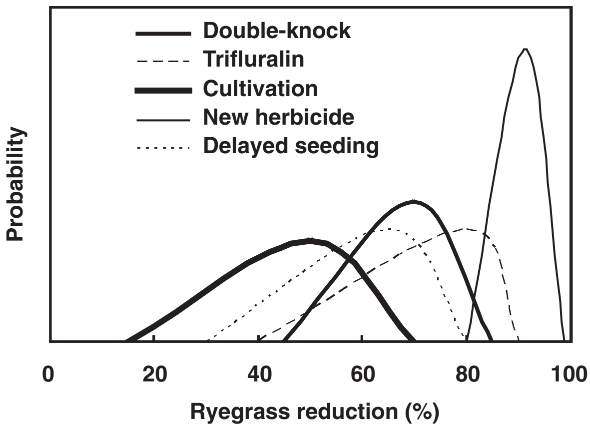

Figure 2. Probability density functions for the perceived ryegrass control achieved from 5 weed control practices. Triangular distributions drawn using the median of the most likely percentage control, the lowest possible and highest possible percentage control values elicited from growers.

selective herbicides was demonstrated, with the modal level of ryegrass control being 90% and the lowest expected percentage control being substantially higher than any other practice shown at 80%. In contrast, the 'traditional' weed control methods of stubble burning (Fig. 1) and cultivation (Fig. 2) had much lower perceived modal efficacy and large variances.

Although not classified in this study as an IWM practice, the pre-emergence herbicide trifluralin was included for comparison. Trifluralin is a widely used herbicide for ryegrass control in cereals. Its use has increased as resistance development to post-emergence selective herbicides has become more widespread. The distribution shows the mode expected efficacy to be about 80% (Fig. 2). However, the distribution also suggests a considerable perceived probability that the control percentage will be below 50%. Similarly, double-knock, an IWM practice based on the use of non-selective herbicides, was perceived to have a higher variance in reducing in-crop weed numbers.

The calculated expected values (distribution means) from growers' subjective probability distributions for percentage control are shown in Table 4. Of the 10 practices, the post-emergence selective herbicide had the highest expected percentage control (86%). Non-herbicide practices had the lowest mean expected percentage control (burning, cultivation and high sowing rate). The post-emergence selective herbicide also had the lowest coefficient of variation (CV). This indicates that, on average, individual growers have a high level of certainty that the modal level of expected control will be achieved. The practices with the highest perceived variance in control (CV) were the 3 non-herbicide practices: burning, cultivation, and high sowing rates.

Growers who had used cultivation and high sowing rates in the past 4 years (users) had a higher mean expected percentage control than non-users (Table 4). In DAL, non-users of high sowing rates perceived a higher variance in percentage control than users of high sowing rates. Regional factors were also shown to influence the perceived efficacy of catching, with growers in DAL perceiving a higher variance than growers in KAT. For all practices, except high-sowing rate, there was no significant difference in perceived variance of control between users and non-users.

Table 4 shows the mean expected percentage control for a range of practices and the standard deviation of this mean. This gives an indication of the dispersion between growers, or the similarity of their perceptions about the expected percentage control for the different practices (not to be confused with the CV shown in Table 4, which indicates the

Table 4. Perceived efficacy of ryegrass control practices, as measured by expected percentage control and the coefficient of variation, calculated from the elicited subjective probability distributions

Practice	Expected percentage control[A]	Coefficient of variation (%)
Stubble burning	47 ± 19	24
Catching	57 ± 15	KAT: 14 /DAL: 18**
Cultivation	Users: 49 ± 21 / Non-users: 39 ± 22** KAT: 39 ± 23 / DAL: 50 ± 19***	23
High sowing rate	Users: 35 ± 19 / Non-users: 28 ± 17**	DAL Users: 20 / DAL Non-users: 30[B] KAT Users: 25 / KAT Non-users: 24[B]
Delayed sowing	55 ± 23	17
Double-knock	64 ± 21	14
Croptopping	62 ± 17	19
Manuring	74 ± 19	12
Trifluralin	67 ± 14	15
New herbicide	86 ± 10	7

[A]Values for Users/Non-users and KAT/DAL shown where 2-way ANOVA shows a significant difference; values are mean ± s.d.
[B]Significant interaction between Region and Use (P<0.001), based on 2-way ANOVA.
*P<0.05; **P<0.01; ***P<0.001.

perceived variance for individual growers). The non-IWM practice, post-emergence selective herbicide (new herbicide), had the lowest standard deviation (highest consistency of perceptions among the growers), with a value of 10.

Awareness of IWM practices. The results above include the responses from growers who provided the necessary 3 pieces of information required to produce the triangular distribution of percentage control. Some growers were unable to provide all 3 values for all practices. Reasons for this were not recorded. Reasons stated by growers included not being aware of the practice and/or not having sufficient knowledge of the practice to offer expected percentage control figures.

There were also some growers who were aware of practices and, in some cases, using the practice, who did not believe they had sufficient quantitative knowledge of the ryegrass control achieved by the practice. In general, the proportion of growers who did not provide distributions is low. At most, 12 out of the 132 growers (9%) could not, or did not, provide the necessary data. There is no obvious association between region and the proportion of growers not providing distributions for the IWM practices. There are, however, differences between the practices in terms of the number of distributions not provided. Associated with this are differences between users and non-users of the practices.

All users were able to provide an efficacy distribution for catching, croptopping and manuring. In contrast, at least 10 non-users (about 11% of non-users for each practice) did not provide a complete response for these 3 practices. It was not recorded whether a grower was a user or non-user of trifluralin. It would, however, be expected that the majority of growers would have used trifluralin in the past 4 years. All but 3 growers provided a perceived ryegrass control distribution for a hypothetical new herbicide with a novel mode of action, described as having characteristics similar to an existing selective herbicide.

Perceptions of value. Overall, the only practices with a mean value rating not less than an effective post-emergence selective herbicide (i.e. a rating of at least 5) were the pre-emergence herbicide trifluralin and the non-selective herbicide-based treatment, double-knock (Table 5). Growers with a herbicide resistant weed population on their farm perceived burning, double-knock, green manure and trifluralin to be of significantly (P<0.05) greater value than those without resistance. Differences between growers with and without a herbicide resistant weed population on their farm were near significance at the 5% level for catching (P = 0.05) and croptopping (P = 0.06). Growers with resistance generally perceived IWM practices and trifluralin to be of greater value. In all cases, growers who had used a particular practice in the past 4 years perceived the practice to be of greater value than those who had not used the practice.

Discussion

Adoption of integrated weed management practices

All growers employ some practices that can be classified as contributing to IWM. Some of these practices may not be used primarily for weed control or rated highly for their weed control efficacy or value. Growers with some level of herbicide resistance on their property are more likely to also use practices that offer few benefits other than weed control (primary practices). The results of factor analysis supported this categorisation, identifying primary practices that are commonly used on the same property. Harvesting low and burning windrows, catching and croptopping are examples of primary practices. Unlike practices such as stubble burning and cultivation, these practices are likely to be used primarily for ryegrass control purposes.

Differences between growers of crops with and without resistance are smaller for practices often associated with less intensive cropping (e.g. heavy grazing, pasture phases and hay production). The main reason for use of these practices

Table 5. Mean value ratings for ryegrass control practices

A 2-sample Wilcoxon rank-sum (Mann-Whitney) test was used to determine whether distributions of users *v.* non-users and growers with herbicide resistance (HR) *v.* no herbicide resistance (NoHR) come from the same distributions

Practice	Practice use			Resistance status	
	All	Users	Non-users	HR	NoHR
Stubble burning	3.7 ± 1.91	4.1	2.2***	4.1	3.0***
Catching	4.2 ± 1.97	5.5	4.0*	4.4	3.8
Cultivation	3.1 ± 1.51	3.5	2.5**	3.1	3.9
High sowing rate	4.2 ± 1.76	4.7	3.5***	4.4	3.8
Delayed sowing	4.3 ± 1.85	5.1	3.7***	4.4	4.1
Double-knock	5.5 ± 1.77	5.9	4.9**	5.8	5.0**
Croptopping	4.5 ± 1.80	5.0	4.3*	4.8	4.2
Manuring	4.2 ± 2.04	5.6	4.0**	4.5	3.8*
Trifluralin	5.0 ± 1.74	—	—	5.3	4.6*

*P<0.05; **P<0.01; ***P<0.001.

may not be ryegrass control, nor even general weed control. In many cases, their use could be because they form an integral component of the preferred farming system and provide benefits other than weed control.

Perceptions of integrated weed management practices

Perceptions of efficacy. In general, the average grower's perceptions of IWM practice efficacy are consistent with research and field experience. This is also the case for non-users of the practice, growers of crops with no herbicide resistance and growers from a region with lower levels of herbicide resistance. The characteristics of post-emergence selective herbicides that explain their extensive use (i.e. high and consistent weed control) have been demonstrated in this study.

No IWM practice or alternative pre-emergence selective herbicide was perceived to offer the efficacy or reliability of a post-emergence selective herbicide. The results indicate that the mean expected efficacy of selective herbicides was high, but also that a very high proportion of growers agree that this is the case. The risk of lower control, or more variable control, provided by alternative herbicides (such as trifluralin) and non-selective herbicides, relative to the post-emergence selective herbicides, may be of particular importance when growers no longer have the post-emergence selective herbicide option, due to resistance.

The practice of manuring was perceived to have a modal efficacy of 80% and similar variation to most other IWM practices. This is an unexpected result, given that manuring involves the sacrificing of a crop using mechanical and/or herbicidal means, resulting in no grain being harvested. Research into the practice generally concludes that near 100% ryegrass seed set control can be practically obtained (assuming herbicide control of any plants surviving green-manuring). Perceptions of manuring efficacy suggest an opportunity for information to improve decision making.

The difference in mean expected percentage control for cultivation may be explained by the fact that growers who stated they have used 'cultivation to kill weeds' are likely to consider a form of cultivation that offers greater percentage control than the form of cultivation considered by non-users. This may be partly the result of greater knowledge of how to gain a higher level of weed control, acquired through learning-by-doing.

A grower's CV for percentage control could comprise both uncertainty about the effectiveness of the practice and also known variability (or risk) regarding the practice's effectiveness. In the case of the latter, seasonal and environmental factors are possible causes of any such variability. Given that growers with a higher level of information about the efficacy of practices (users) generally do not have significantly different CVs from non-users, it would seem possible that most of the perceived variance in efficacy could be explained by factors other than lack of information.

The provision of perceived distributions for ryegrass control suggests that not more than 9% of growers are in a stage of the adoption process before non-trial evaluation for any of these practices. They may be at either the pre- or post-awareness stage. Allowing for an estimated 4 growers who did not provide a response for reasons other than uncertainty or lack of awareness, this figure is more likely to be about 6%. This suggests that the adoption process has advanced beyond awareness of the practice to at least the non-trial-evaluation stage, for almost all growers. This applies even to practices that are used by a small proportion of growers (such as manuring and catching).

As a general statement, non-users of IWM practices appear well informed of the efficacy of the IWM practices. There is no example where the perceptions of non-users are notably different from users and also fall outside of the range deemed to be consistent with research findings (e.g. Gill and Holmes 1997; Matthews *et al*. 1996). The results suggest, however, that there is potential for non-users of high sowing rates to increase their perceived percentage control.

Given the differences in environment between the KAT and DAL regions, the efficacy of the practices could be expected to differ markedly. The lower proportion of growers in the KAT region who have used some of the practices could also be expected to result in differences in the knowledge of the practices. There is, however, no clear example of a practice in which growers in a region hold misperceptions or have exceptionally high uncertainty in terms of a practice's efficacy. In general, growers appear well informed of the efficacy of IWM practices.

Perceptions of value. The results demonstrate the high perceived cost-effectiveness of herbicide-based practices for ryegrass control. Despite their extensive use, stubble burning and cultivation had the lowest mean value score. This is consistent with their classification as secondary practices. That is, they are practices that are commonly used, but often not primarily for their weed control value.

As with the perceptions of efficacy, it cannot be concluded in a cross-sectional study that high perceived value has led to adoption. It is possible that growers adjusted their perceptions post-adoption. This may have occurred through learning, practice development or a process relating to cognitive dissonance (Festinger 1957), where people are sometimes observed to revise their beliefs to be more consistent with their existing behaviour, rather than with their experience or other evidence.

Conclusions

All growers used several IWM practices, although some practices were only likely to be adopted once herbicide resistance had become a problem. Many IWM practices are perceived to be costly and unreliable, relative to major selective herbicides. Although growers were generally well informed of the efficacy of the IWM practices, the findings of this study do suggest an opportunity to influence growers' perceptions of the overall value of some practices and their subsequent adoption. This may not necessarily involve increasing a practice's perceived weed control efficacy or value for weed control alone.

Some integrated weed management practices that do not offer high weed control efficacy are extensively used by growers. Demonstrating benefits that may add to the overall utility of a practice in the farming system, other than just weed control benefits, could be an effective avenue to increasing adoption. For example stubble burning can have benefits for disease control and machinery clearance, in addition to weed control; catching has benefits for fodder collection; delayed sowing has occasional benefits for decreasing frost-risk; and croptopping can offer more even crop maturation. For weed scientists and extension agents, greater adoption of IWM practices by growers of crops without a serious herbicide resistance problem may be best achieved through greater emphasis on a farming systems approach to research and extension for IWM practices.

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Appendix. A description of integrated weed management practices

Practice	Definition/description
Autumn tickle	The use of scarification/cultivation (usually light) to stimulate weed germination, allowing for a higher proportion of weeds to be killed non-selectively before sowing.
Barley for weed control	Barley is a crop that is competitive against weeds (Matthews *et al*. 1996). Weed control can be a major reason for its use, as it allows for effective use of pre-emergence herbicides (i.e. trifluralin) and a shorter growing season which, in turn, allows for greater pre-sowing weed control.
Catching	The use of a cart trailing the harvester to collect material, including weed seeds, that passes through the harvester (in some cases sieved material is caught in a bin fixed to the harvester). The captured material is then dumped and often burnt.
Croptopping	The application of a non-selective herbicide (usually paraquat-based) to mature or near-mature crops, to reduce viable seed set in weed species. Mainly performed in lupin crops.
Cultivation	The use of cultivation to kill germinated weeds.
Delayed sowing	Deliberate delay of crop sowing for 2 weeks or more, to allow for additional weeds to be non-selectively (in this case defined as a non-selective herbicide) killed pre-sowing.
Double-knock	Use of a second treatment to kill survivors to an initial treatment, in this case defined as a glyphosate application followed by a paraquat-based application to control weeds before sowing. The practice can provide higher levels of pre-sowing weed control, yet not select for glyphosate resistance (Diggle and Neve 2001).
Harvest low–no spread–burn	A practice involving 3 stages whereby crop harvesting is performed at a lower than usual height, to maximise the amount of crop residue and weed material that passes through. Rather than being spread over the paddock, this is placed in rows that provide for greater fuel for greater fire temperature.
Hay	The production of hay from a crop. This is generally done before in-crop weed maturation.
Heavy grazing	Timely intense grazing of paddocks not sown to crop with sheep can reduce weed seed set and weed seed return to the seed bank.
High wheat sowing rate	High wheat sowing rates are used to produce a higher crop plant density that can reduce yield loss due to weeds and suppress weed seed production.
Fallow	The maintenance of land free of living plants using herbicide or cultivation means, usually for a period in summer–autumn before crop sowing.
Manuring	The pre-maturity sacrifice of a crop using herbicide (brown manuring) or mechanical (green manuring) means to prevent weed seed set and return organic matter to the soil.
Mechanical pasture top	Seed set in pasture can be prevented or reduced by slashing the pasture before weed maturity. Limits to the width of machinery mean that it is usually only performed on small areas.
Pasture phase (treated)	The use of a pasture phase of 2 years or more treated as above to reduce the weed seed bank before a cropping phase.
Spraytopping	The application of a low rate of non-selective herbicide to pastures timed to reduce viable seed set in weed species.
Stubble burning	The burning of residue, usually in autumn, to reduce the level of organic matter on the soil surface, including viable weed seeds. Defined here as the burning of a whole paddock, as opposed to small heaps or patches, of crop residue.
Swathing for weed control	Some crops, such as canola, are cut very near full maturity and left to dry in rows to reduce seed shatter. This can reduce the amount of viable seed set. For the purpose of additional weed control, the process can be done earlier than usual, lower than normal, and in crops that do not usually require swathing.