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Managing the Herbicide Resource: An Evaluation of Extension on Management of Herbicide-resistant Weeds

Rick S. Llewellyn
CSIRO Sustainable Ecosystems, Adelaide

David J. Pannell
University of Western Australia, Perth

The threat of herbicide-resistant weeds to crop production makes sustainable weed and herbicide management an important issue for agricultural extension agencies throughout the world. In this study, we examined the effectiveness of an intensive training workshop in modifying the weed-management-related perceptions and adoption intentions of farmers. We found that the extension activity had significant impacts on farmers' perceptions about several aspects of the herbicide resource management decision, including the speed of resistance development, the potential for a population of herbicide-resistant weeds to return to herbicide-susceptibility, and the economic value of several treatments. As a consequence, the workshop appears to have altered the adoption intentions of a significant number of participating farmers, including adoption of a strategy to prevent development of resistance to the herbicide glyphosate. We argue that extension can be more effective if it targets grower perceptions identified as being influential in the adoption decision, particularly if those perceptions are known to be inaccurate.

Key words: adoption, decisions, herbicide resistance, integrated weed management, IWM, integrated pest management, IPM, perceptions.

Introduction

Pests and weeds can develop resistance to pesticides and herbicides soon after they are introduced. This is demonstrated by early reports of insecticide resistance (Melander, 1914) and herbicide resistance (Ryan, 1970). In some cases the first observations of resistance to a particular herbicide have occurred around the same time as its local commercial release (e.g., Heap & Knight, 1990). In other cases it has taken decades (e.g., Powles, 2008). Herbicide-resistant (HR) weeds are now widespread (Heap, 2009) and are a complex farm management issue (Pannell & Zilberman, 2001).

The rapidly increasing availability of HR crops has added to the complexity and importance of managing herbicide-resistance risks. Although the ecological essence of the problem remains the same (weed populations will evolve resistance to herbicides when exposed to repeated selection pressure), HR crops have introduced new avenues to apply certain herbicides and select for resistance. This has seen HR weeds become an issue of increasing concern in regions where resistance was previously not a major consideration (Cerdeira & Duke, 2005; Owen & Zelaya, 2005). The economic importance of crops with resistance to specific herbicides (Brookes & Barfoot, 2006) has also increased the potential economic impacts of weed resistance to those herbicides.

In this article, we examine decision making about herbicide-resistance management at the farm level, focusing on the implications for agricultural extension. The research comes from a major Australian cropping region where there has been long-term experience dealing with widespread and severe resistance to important crop-production herbicides (Owen, Walsh, Llewellyn, & Powles, 2007; Powles, Preston, Bryan, & Jutsum, 1996). A range of factors influencing the adoption of a suite of weed control practices for herbicide-resistance management by grain growers has been identified in this region (Llewellyn, Lindner, Pannell, & Powles, 2007). These are referred to in this article as integrated weed management practices (IWM) and are essentially non-herbicide treatments combined with some herbicide-based treatments that can reduce the selection pressure for herbicide resistance.

The article begins with an overview of the resource management-based approach used to consider herbicide use and resistance management decisions in this study. This is followed by results from an empirical study where the influence of extension and learning on aspects of the herbicide-resistance management and IWM adoption problem are evaluated. Implications for improved herbicide- and weed-management strategies in the presence of herbicide-resistance risks are discussed.

The Herbicide-Resistance Management Problem

Among the first to demonstrate the relevance of resource economics to the pesticide-resistance problem were Hueth and Regev (1974). Referring to insect pests, they argued that while pests have been viewed (by economists at least) as being equivalent to a renewable resource, the effectiveness of pesticides against those pests is a potentially exhaustible resource that also requires management.

Using a resource approach (see also Miranowski & Carlson, 1986), pest susceptibility is viewed as a resource stock that can be considered similar to resource stocks in other extractive industries. Application of the pesticide, and the consequent selection for pest resistance, is analogous to a form of extraction. The key question then becomes one of optimal extraction rates—how much pesticide susceptibility to extract now and how much to conserve for later.

To reduce selection pressure for resistance (rate of extraction) farmers need to adopt certain IWM practices that reduce reliance on particular herbicides. Therefore, the adoption decision for IWM practices depends not only on characteristics of the IWM practices but also on factors relating to the management of an herbicide resource. These latter factors can include the following topics.

Rate of Depletion

The potential for herbicide resistance in target weeds to deplete the stock of herbicide susceptibility is widely observed (Heap, 2009), and resistance to multiple herbicides can greatly limit weed control options (e.g., Owen et al., 2007). The key question is not whether it is possible for resistance to develop, but rather how rapidly resistance will develop under different herbicide use and agro-ecological scenarios. Different weed-herbicide combinations have widely varying propensities to lead to resistance.

Another possible source of depletion is through mobility. In economic analyses of herbicide resistance, it is most commonly assumed that weed mobility is of negligible importance, so that weed susceptibility can be managed as a private property resource (e.g., Pannell et al., 2004). In reality, weeds do exhibit some mobility through seed import and pollen flow carrying resistant genes (e.g., Busi, Yu, Barrett-Lennard, & Powles, 2008; Lu, Baker, & Preston, 2007) and it can be common for farmers to expect some weed problems, including herbicide resistance, to be introduced via neighbors (Llewellyn & Allen, 2006). If growers see resistance development as an open-access resource problem, this reduces their incentive to act to prevent resistance developing, as such efforts would prove fruitless if resistance is subsequently introduced from other sources.

Rate of Renewal

Renewal of susceptibility to herbicides can occur if a new herbicide becomes available that can control weeds that have previously evolved resistance to herbicides. If a farmer expects new herbicide technologies to become available in the future, this reduces the incentive that they have to preserve the herbicide susceptibility of weeds in the short term.

Another factor that can lead to renewal of herbicide susceptibility is regression of herbicide resistance. This is where the proportion of resistant plants in the weed population declines once the herbicide selection pressure is removed, allowing herbicide effectiveness to return. This may occur naturally if the resistant plants incur a fitness penalty relative to susceptible plants, as is the case with weeds that are resistant to triazine herbicides (Gressel & Segel, 1990). There is also evidence of fitness penalties causing resistance regression in some glyphosate-resistant weed populations (Preston, Wakelin, Dolman, Bostamam, & Boutsalis, 2009). However, not all HR weeds suffer such a fitness penalty. For example, studies of the most common forms of resistance affecting annual ryegrass in Australia (Owen et al., 2007) have not found substantial fitness penalties (Gill, 1995; Holt & Thill, 1994).

Uncertainty and Learning in Adoption of Integrated Weed Management Practices

The adoption of agricultural innovations is commonly assumed to be a decision process involving learning and uncertainty (e.g., Abadi Ghadim & Pannell, 1999; Fischer, Arnold, & Gibbs, 1996; Pannell et al., 2006). Essentially, learning in the adoption process involves the acquisition of information that is assimilated to update existing perceptions about the characteristics of an innovation that determine its attractiveness to the potential adopter. The importance of such innovation-specific farmer perceptions in adoption decisions has been demonstrated in many empirical studies (e.g., Adesina & Baidu-Forson, 1995; Cary & Wilkinson, 1997).

Applying the learning model of Lindner and Gibbs (1990) to the example of IWM practice efficacy, it can be assumed that the actual percentage of weed control achievable by adopting an IWM practice has a distribution with a mean percentage of control and associated variance due to risk factors such as seasonal conditions. The grower is assumed to be imperfectly informed about the efficacy of the practice, and therefore holds their own prior perception about likely percentage of control with its mean and variance. The variance may comprise a component relating to exogenous risks such as seasonal conditions and a component reflecting the subjective uncertainty resulting from a lack of information (Tsur, Sternberg, & Hochman, 1990). It is the latter component that can be influenced by information and learning relating to the IWM practice.

Information gained by the grower about the efficacy of the practice is assumed to have its own mean and variance. Low variance can be interpreted as a measure of the precision or informativeness of the message (Lindner, Fischer, & Pardey, 1979; Stoneman, 1981), and this impacts the potential of the information to influence the grower's perceptions. The effectiveness of pieces of information from different sources is likely to vary (Fischer et al., 1996). Effectiveness can be influenced by factors such as perceived validity (Leathers & Smale, 1992) and locational relevance (Lindner, Pardey, & Jarrett, 1982).

Those growers not yet using the IWM practice on their farm must rely on off-farm sources of information, unless they conduct a field trial of the practice themselves. Marra, Hubbell, and Carlson (2001) argued that information generated on the decision-maker's own farm, such as that produced by past use of an innovation or a trial, would be weighted most heavily in terms of effectiveness relative to other information sources in the decision to adopt a cropping innovation. New information with high perceived effectiveness and a mean that differs largely from the grower's prior mean will have the most influence on the grower's perceptions. The methodology below describes how the influence of extension information on perceptions relating to herbicide-resistance management decisions was measured.

Methods

The study examines in detail the impact of a particular extension event on farmer perceptions relating to the effectiveness of IWM practices. A sample of growers was surveyed both before and after an extension workshop to identify their perceptions in relation to a number of aspects of herbicide resistance and integrated weed management.

Experimental Design

A pre-test/post-test experimental design was used with a one-year period between the initial measurement of growers' perceptions in March 2000 (see also Llewellyn et al., 2005; Llewellyn et al., 2004) and the final measurement in March 2001. A subset of growers was exposed to an extension treatment in the form of a workshop conducted in October 2000, as described in the next section. Measurement of perceptions for both participants and non-participants allowed changes attributable to the workshop and to other sources to be explained. A disadvantage was the inability to account for 'information leakage:' perception changes by non-participants that are a result of communication with participants (de Vaus, 1995). Hence, the influence of the workshop on perceptions in the region may be underestimated, since the measured differences between participants and non-participants would be reduced by any leakage.

The influence of the workshop on perceptions was determined using Ordinary Least Squares regression, with the pre-test perception included as an explanatory variable of the post-test perception. Equation specification recognized that the adjustment of prior perceptions to information may be dependent on farm and farmer-specific factors.

Sources of information in addition to the workshop, such as extension agents and learning from on-farm experience, may also have contributed to adjustments to the perceptions of growers. Hence, an information exposure index based on various sources of farm-specific (level of agronomist and crop consultant use) and non-farm-specific (publication subscriptions and grain grower group participation) cropping information was developed for each grower using principal component analysis (described in Llewellyn et al., 2007). Recognizing the role of on-farm learning, the confirmed use of an IWM practice during the 12-month period is also included in the regressions, separately from this information exposure index. A measure of human capital was developed, but not included as an explanatory variable of post-workshop perceptions because it had no significant influence on changes in perceptions.

The Workshop

In each region, two half-day workshops for separate groups of growers were held on two consecutive days during October 2000 in computer-equipped workshop venues in the largest centrally located town in the study region. All participants in the 2000 survey received an invitation. Targeted information relating to specific IWM and herbicide-resistance factors was presented by a well known researcher in the field of herbicide resistance and its management.

The workshops also included an active learning session using a computer-based bioeconomic model known as Resistance Integrated Management, or RIM (Pannell et al., 2004). RIM-based workshops have been successfully run with numerous farmer groups in Western Australia (Stewart, 2000). In the workshop, growers used RIM to test various IWM strategies and crop rotations for profitability and ryegrass population management over a 10-year period. The objectives were to actively reinforce extension messages by simulating herbicide-resistance management strategies that had been discussed, and to demonstrate decision-making based on knowledge that selective herbicides are potentially a finite, exhaustible resource.

Sample and Surveying

The prior perceptions used in this analysis are those elicited from a survey of 132 randomly selected grain growers from within the Dalwallinu (DAL) shire (64 growers) and Katanning-Woodanilling (KAT) shires (68 growers) of Western Australia; the survey was conducted prior to crop seeding in February/March 2000. The two regions represent an area of the Western Australian wheatbelt with intensive cropping and where herbicide resistance is well-established (DAL) and an area where cropping has only relatively recently become more intensive and weed populations with high levels of herbicide resistance are not yet widespread (KAT). Most questions in the questionnaire focused on herbicide resistance and management of the crop weed annual ryegrass (*Lolium rigidum*) and resistance to post-emergence ryegrass-selective herbicides. This represents the most common form of herbicide resistance in Western Australia (Owen et al., 2007).

Perceptions of the control percentage provided by various IWM practices and perceptions relating to herbicide resistance (except the perceived chance of resistance reversion) were elicited using triangular subjective probability distributions. For example, the distribution for perceived efficacy of a practice was elicited by asking for the 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 value for percent control and variance in control were then calculated for the distribution (see Hardaker, Huirne, & Anderson, 1997). The IWM practices were weed seed catching at harvest (catching), weed seed kill prior to harvest with a low-resistance risk herbicide (croptopping), crop sacrifice by mechanical or herbicidal means (manuring), delayed crop seeding, the use of two low-risk herbicides to control weeds prior to seeding (double knockdown), and higher wheat seeding rates. For perceptions about these practices, changes in both the expected value (EV) and coefficient of variation (CV; as a measure of uncertainty) are considered.

From the 132 farm businesses involved in the initial survey, 31 growers attended the workshops. In March 2001 return surveying was conducted, with 101 growers resurveyed. All interviews were conducted by a primary or second interviewer. A different second interviewer was used in 2001. To allow for some account to be taken of possible interviewer bias, growers who were interviewed by the primary interviewer in 2000 were interviewed by the same interviewer in 2001. The analyses included 27 workshop participants, with 70 usable observations for non-participants. In some analyses, non-response to particular questions has resulted in a reduced number of useable observations. The question formats used to elicit perceptions and adoption levels were identical in both surveys.

Self-selection for workshop attendance needs to be considered. Farm and farmer characteristics that influence adoption can also be associated with attendance at extension events (Goodwin & Schroeder, 1994). There was no notable difference between the two regions in the mean time required to travel to the workshop venues. We conducted a logit analysis (data not shown) to determine the influence on the likelihood of workshop attendance with a range of variables including age, education, herbicide resistance status, and farm size. Growers with a higher exposure index (described above) were found to be more likely to attend ($P = 0.02$), suggesting that they are likely to be more active information-seekers. This was the only variable significant at the 5% level.

Results

A fundamental assumption of the probability revision framework is that prior perceptions condition posterior perceptions. The null hypothesis that growers' prior perceptions are not associated with post-workshop perceptions is consistently rejected in this study. As expected, the prior perceptions and pre-workshop adoption intentions measured in Year 1 are consistently significant in explaining the post-workshop perceptions measured in

Table 1. Models of growers' perceptions in Year 2 of the expected number (EV) and uncertainty (CV) of herbicide applications before resistance develops, using OLS regression.

	Diclofop		Glyphosate	
Variable	**EV**	**CV**	**EV**	**CV**
Workshop (1/0)	-0.79 (0.43)*	-1.49 (1.47)	-2.65 (3.08)	-3.55 (2.93)
Information exposure	-0.27 (0.25)	-0.51 (0.84)	-1.33 (1.80)	0.25 (1.66)
Prior perception	0.36 (0.10)***	0.30 (0.11)***	0.55 (0.12)***	0.29 (0.12)**
Interviewer (1/0)	0.67 (0.38)*	-2.57 (1.29)**	10.27 (2.71)***	4.68 (2.58)*
Constant	3.90 (0.69)***	12.79 (1.89)***	7.70 (2.74)***	13.97 (2.79)***
Obs.	96	96	94	94
F	5.57***	3.21**	8.32***	2.29*
Adjusted R^2	0.16	0.10	0.24	0.05

** P < 0.1; ** P < 0.05; *** P < 0.01 (standard errors shown in parentheses)*

March 2001 (Tables 1, 2, and 3). The results also demonstrate the value of accounting for interviewer bias. In several models the variable identifying the interviewer in Year 2 is significant. There appears to be no consistent pattern to the direction of this influence, although it appears that slight inconsistencies in the presentation of different questions are being captured.

Although all models presented are statistically significant in explaining Year 2 responses, several models account for only a small proportion of the response variance (indicated by the R^2-type measures in Tables 1-3 and 5-6). This suggests that other unspecified farm or farmer variables influenced responses and/or measurement error in the elicitation process and a stochastic element in the elicitation of growers' responses. Comparable studies examining perception changes have reported difficulties in measuring perception changes (McDonald, Glynn, Hoffmann, & Petzoldt, 1997; Verstegen, Sonnemans, Huirne, Dijkhuizen, & Cox, 1998). The implications of this are discussed in the next section.

Perceptions of Herbicides and Resistance

The workshop included information relevant to growers' perceptions about onset of resistance, herbicide resource depletion, and renewal of the herbicide resource (Llewellyn, Lindner, Pannell, & Powles, 2001). Specifically, it included a presentation of current knowledge about the number of years until resistance develops, as well as about the number of years until a new herbicide that is effective against weeds resistant to old herbicides is likely to become available. Other key information provided concerned the probability of a resistant ryegrass population reverting over time to susceptibility to old herbicides. The workshop also presented an opportunity to influence growers who perceived that an exceptionally high number of herbicide applications could be used before resistance would develop. The workshop presented credible scientific and field knowledge regarding the number of effective applications of the herbicide diclofop that could be applied. Results from glyphosate-resistance modeling were presented (Neve, Diggle, Smith, & Powles, 2003), but it was acknowledged that there was less scientific evidence available concerning the development of resistance to this major non-selective herbicide. Therefore, it was expected that the workshop would be more influential in changing perceptions about onset of diclofop resistance than about glyphosate resistance.

Workshop attendance had a statistically significant (P < 0.1) negative influence on growers' expectations about the number of applications before a ryegrass population becomes resistant to the herbicide diclofop (Table 1). Participation in the workshop had no statistically significant impact on the equivalent perceptions about the herbicide glyphosate or about the CV for either herbicide (Table 1), although the sign was negative in all cases. The results suggest that perceptions of the relationship between resistance selection pressure (applications) and resistance development can be influenced by the extension of credible scientific information.

A relatively large amount of time at the workshop was spent discussing the development of new herbicide

Table 2. Models of growers' perceptions in Year 2 of the number of years until a new selective herbicide becomes available, using OLS regression for expected value (EV) and coefficient of variation (CV), and the probability of a resistant ryegrass population reverting to susceptibility.

	Years until new herbicide		Probability of resistance reversion
Variable	**EV**	**CV**	
Workshop	0.98 (1.80)	-4.93 (2.72)*	-1.42 (0.59)**
Information exposure	-0.46 (1.03)	0.30 (1.55)	-0.46 (0.33)
Prior perception	1.48 (0.26)***	0.34 (0.11)***	0.36 (0.09)***
Interviewer	2.42 (1.58)	2.86 (2.36)	-1.07 (0.53)**
Constant	-0.44 (1.89)	18.20 (3.06)***	2.19 (0.48)***
Obs.	97	97	96
F	9.53***	3.97***	10.54***
Adjusted R^2	0.26	0.11	0.29

** P < 0.1; ** P < 0.05; *** P < 0.01 (standard errors shown in parentheses)*

products and on possible constraints to new herbicide development and the timeframes observed from discovery to release. It was expected that the information presented at the workshop would act to increase growers' perceptions about the expected number of years until a new herbicide becomes available. This perception is a significant determinant of IWM adoption (Llewellyn et al., 2007).

Workshop participation did not have a statistically significant influence on perceptions about the expected number of years (EV) until a new herbicide becomes available (Table 2) but reduced the uncertainty (CV) about when an herbicide with a new mode of action for selective ryegrass control would become available. A possible explanation for the reduction is that the amount of detailed information presented at the workshop made growers both more aware that chemical companies are likely to develop new herbicides and that it is a lengthy process to do so.

At the workshop, reasons why ryegrass populations resistant to particular herbicides have not reverted to susceptibility were explained; also, the workshop presented a simple message that the probability of this form of resistance regression occurring is very low, that a field example has never been confirmed, and therefore that resistance to herbicides like diclofop in ryegrass should be considered permanent. In the initial survey, many growers held perceptions contrary to scientific knowledge about this topic. Therefore, workshop participation was expected to reduce the perceived probability of a resistant population returning to susceptibility.

As expected, workshop participation was found to be significant in reducing the perceived probability of a resistant population returning to susceptibility (Table 2). The 'workshop' coefficient shows that the influence of workshop attendance was to reduce the perceived probability of a resistant population returning to susceptibility by 0.14 (i.e., 14 percentage points). This relatively large shift in perception demonstrates the potential influence of information when a simple and certain message can be delivered to an audience holding misperceptions with a low level of certainty.

Perceptions About the Efficacy and Value of Integrated Weed Management Practices

At the workshop, information based on research results about the efficacy (percentage of control) and overall value of the following IWM practices was presented, including

- high wheat seeding rates (>65 kg/ha),
- the double-knockdown technique (the use of two non-selective herbicides with low resistance risks prior to crop seeding),
- croptopping (the use, usually in non-cereal crops, of a low-resistance-risk herbicide before harvest to prevent weed-seed set),
- manuring (sacrificing a crop by herbicide or mechanical means), and
- catching (machinery used to capture weed seeds in the harvest operation).

In three of the four workshops held, participants who had used the catching technique contributed information highlighting the management difficulties associated with catching and experience with high variation in efficacy. Workshop participants discussed reasons for expectations of croptopping control to be lower in growers' paddocks than in research plots (e.g., uneven crop and weed ripening over large paddocks).

In the regressions, an additional binary explanatory information variable (1 if used in past year) was included to identify growers who used the practice in question during the 12-month period between the initial and final surveys. This recognizes the potentially important role that recent on-farm experience with the practice after the initial survey can have in influencing perceptions. Late opening rains meant that the feasibil-

Table 3. Models of growers' perceptions in Year 2 of the value of IWM practices for ryegrass control using OLS regression.

Variable	High seed rate	Double knock	Manure	Crop-topping	Catch	Delayed seeding
Workshop	0.41 (0.30)	0.69 (0.38)*	0.57 (0.48)	0.11 (0.38)	-0.33 (0.42)	-0.13 (0.48)
Information exposure	0.13 (0.17)	0.25 (0.23)	0.24 (0.28)	0.15 (0.23)	0.01 (0.25)	0.42 (0.27)
Prior perception	0.61 (0.08)***	0.19 (0.09)**	0.29 (0.10)***	0.53 (0.10)***	0.26 (0.09)***	0.23 (0.11)**
Used in past year	-0.15 (0.29)	0.34 (0.36)	1.44 (0.50)***	0.74 (0.37)*	0.30 (0.69)	1.02 (0.58)*
Interviewer	-0.03 (0.29)	-0.19 (0.34)	-0.99 (0.43)**	-0.57 (0.36)	-0.50 (0.37)	-0.26 (0.42)
Constant	2.33 (0.33)***	4.26 (0.52)***	3.43 (0.52)***	2.49 (0.47)***	3.25 (0.44)***	3.51 (0.53)***
Obs.	97	97	95	92	95	97
F	15.41***	3.55***	4.09***	8.17***	2.42**	2.19*
Adjusted R^2	0.43	0.12	0.14	0.28	0.07	0.06

** P < 0.1; ** P < 0.05; *** P < 0.01 (standard errors shown in parentheses)*

ity of using some early-season practices—such as delayed seeding and double knockdown—was reduced. Intended use and actual use of practices is shown in Table 4.

Since the expected values for percentage of ryegrass control elicited from growers were generally consistent with research information, and CVs for users and non-users were similar, it was not expected that the workshop would result in large changes in the mean or variance (CV) of growers' perceptions about effectiveness. Results elicited in the initial survey on perceived effectiveness of IWM practices and the similarity between users and non-users were presented at the workshops. Factors hypothesized to limit the influence of such information included the large amount of local 'neighborhood' information available and the fact that most growers' prior perceptions of percentage of control distributions were consistent with research knowledge.

As expected, the workshop variable did not have a significant influence (P > 0.1) on percentage of control EV or CV (regressions not presented) for any of the practices. Information exposure and use was also not significant in any regression model. Therefore the study provides no evidence that workshop attendance influenced the perceived mean percentage of ryegrass control attainable (based on the elicited triangular distributions) from these practices or their perceived reliability. Regressions conducted using the growers' modal responses (i.e., the single percent control figure stated as 'most likely') produced similar results.

Table 4. Actual use in Year 1 and intended future use of practices as stated in Year 1 (Intended use_1) and Year 2 (Intended use_2) from binary variables (n=97).

Practice	Intended use_1	Intended use_2	Used in Year 1
		% of growers	
Double knock	57	60	39
Manure	18	12	22
Crop-topping	32	33	27
Catch	9	8	8
Delayed seeding	45	53	14

Perceived Economic Value of Integrated Weed Management Practices

In the survey, growers were asked to consider all of the costs and benefits of using IWM practices and rate their perceived value on a scale of 1 to 9, with 5 being the value of an effective post-emergence selective herbicide. Research results presented included the high value of high seeding rates (and the minimal risk of reduced grain quality) and the low risk of selecting for glyphosate resistance when the double-knockdown practice is regularly used. It was expected that this information would act to increase the perceived economic value of these practices.

Workshop participation had a significant positive influence on the perceived value of the double-knockdown practice (Table 3) and a positive and close-to-significant influence on the perceived value of high wheat seeding rates and manuring. Use of practices in the past year resulted in a statistically significant positive influ-

Table 5. Models of growers' intended average wheat seeding rates (kg/ha), using OLS regression.

Variable	Rate in current year	Expected rate in 4 years' time
Workshop	5.20 (1.90)***	9.13 (3.25)***
Information exposure	1.48 (1.12)	0.26 (2.03)
Expected rate stated in Year 1	0.78 (0.08)***	0.982 (0.15)***
High rate used in Year 1 (1/0)	-	-5.42 (4.14)
Interviewer	-3.21 (1.70)*	-2.91 (2.94)
Constant	19.41 (5.35)***	9.15 (8.56)
Obs.	97	97
F	28.71***	20.79***
Adjusted R^2	0.54	0.51

** P < 0.1; **P < 0.05; ***P < 0.01 (standard errors shown in parentheses)*

ence on the perceived value of manuring, croptopping, and delayed seeding. The information exposure index was not statistically significant for any practice.

In summary, workshop participation positively influenced perceptions about the value of the two practices targeted in the workshop, namely the double-knockdown technique and higher seeding rates. While use of a practice in the past 12 months was shown to be significant for several practices, general information exposure was not significant in influencing the perceived value of any practice.

Changes in Intended Use of Integrated Weed Management Practices

Ultimately, most extension is intended to influence the adoption of practices. Given the short time frame of this study and the one-off nature of the intervention, it was not expected that the workshop would have a notable effect on the number of growers actually using particular practices. In addition, seasonal weather conditions can play a large role in the use of particular practices, thus reducing the likely correlation between workshop attendance and the use of a practice in the following season. For these reasons, the most appropriate measure of the effect of the workshop is intended future use.

In Year 2, growers were asked if practices were intended to be used in the coming season and/or intended to be used in the next four years. Although expected use in the next four years is no guarantee of actual adoption and may suffer from 'yeah-saying' bias, it does at least allow for a more realistic timeframe for changes in adoption behavior. To account for growers who had made the decision to adopt prior to the initial survey, intended use in the coming year or the next four years, as stated in Year 1, was used as an explanatory variable in models of Year 2 adoption intentions.

Adoption of high wheat seeding rates was measured using growers' stated average wheat-seeding rate (kg/ha) and analyzed using OLS regression. All other analyses were performed using logit regressions, with use/not use (1/0), as stated in Year 2, as the dependent variable. Both the identity of the interviewer and the information exposure index were included as explanatory variables. Changes in intended adoption were most expected for those practices where perceptions also were influenced by the workshop (high seed rate and double knockdown).

High wheat seeding rate was a targeted practice at the workshop as it was judged to be of positive economic value to growers. OLS regression analysis was performed on the intended average wheat seeding rate to be used in Year 2 and in four years' time. A binary variable indicating whether growers used a high wheat seeding rate (> 65kg/ha) in Year 1 was included in the model predicting the intended rate in four years' time (as elicited in Year 2). This is intended to account for any on-farm learning during the 12-month period. In each model, the equivalent intended wheat seeding rate (as stated in Year 1) is included as an explanatory variable.

There is strong evidence that the workshop has significantly influenced growers' intentions to use higher wheat seeding rates (Table 5). The coefficients suggest that, on average, a 5.2 kg/ha increase in the Year 2 intended seeding rate and an 8.5 kg/ha increase in the expected rate to be used in four years' time (2005) can be attributed to workshop participation. Although not significant at the 10% level, the use of a high seeding rate in Year 1 appears to have had a negative influence on the intention to use high seeding rates in the future (Table 5). Unlike for other practices, the sign for high seeding rate use in Year 1 was also negative for the perceived value of this practice (Table 3). The negative direction of this variable may be explained by the seasonal conditions, which was an unusually dry season in which high crop density could have exacerbated the effects of water stress on yield and quality.

Logit regression models of intended use of IWM practices other than high wheat seeding rate in Year 2 are presented (Table 6). No model is presented for catching because intended use in Year 2 was perfectly

Table 6. Models of growers' intended use of IWM practices in Year 2, using logit regression (n = 97).

Variable	Double knock	Croptopping	Delayed seeding	Manuring
Workshop	1.52 (0.69)**	0.09 (0.65)	0.39 (0.52)	0.38 (0.70)
Information exposure	1.21 (0.43)***	0.64 (0.436)	0.38 (0.32)	0.15 (0.43)
Use intended in Year 1	1.19 (0.51)**	2.81 (0.60)***	1.29 (0.44)***	1.13 (0.84)
Interviewer	-0.59 (0.53)	0.22 (0.61)	-0.09 (0.46)	1.94 (0.87)**
Constant	-0.22 (0.43)	-2.05 (0.50)***	-0.54 (0.37)	-3.63 (0.87)***
Log likelihood:	-49.2	-39.5	-60.51	-32.0
Chi-square	32.33***	43.98***	13.20**	8.66*
Pseudo R^2	0.25	0.36	0.10	0.12
% correct:[a]	76 (81/69)	85(75/89)	64(65/63)	88 (0/100)

[a] Overall percentage correctly classified (users correctly classified (sensitivity)/non users correctly classified (specificity))

** P < 0.1; ** P < 0.05; *** P < 0.01 (standard errors shown in parentheses)*

predicted by intended use in Year 1, indicating that no grower in the sample was intending to use catching for the first time in Year 2. The workshop variable was significant in explaining intended use of double knockdown in Year 2. Growers with higher information exposure were also significantly more likely to intend to use double knockdown in Year 2. Workshop and information exposure were not significant for the other practices.

In summary, the results suggest that the workshop positively influenced growers' intentions to adopt high wheat seeding rates and double knockdown following the workshop. This may be attributed to the workshop's influence on perception of the economic value of the practices. This was a targeted perception due to its prior identification as being strongly associated with adoption.

Discussion

Most of the workshop information presented about resistance-related factors was found to result in shifts in perceptions amongst the participant population. This was most evident in the case of the probability of resistance reverting to susceptibility. This information was likely to be more influential because few growers held highly developed prior perceptions due to the lack of observable local field experience. Participation in the workshop resulted in a perception of resistance permanence more consistent with research knowledge.

Targeted information also resulted in changes to growers' perceptions of the number of consecutive herbicide applications that could be applied before resistance develops. The high certainty of the information presented, coupled with inaccurate prior perceptions, could explain this result. As particular selective herbicides had rarely been applied consecutively as the only form of weed control in practice, it is likely that many growers did not hold highly developed prior perceptions for this variable.

By contrast, uncertainty and lack of objective verifiable information about the time lag before herbicide companies would release a new herbicide is likely to explain the lack of influence that this information had on growers' perceptions of the mean expected time of new herbicide availability. Notably, general information exposure was insignificant in all models, suggesting that broader information exposure has not played a major role in adjusting perceptions of these very specific herbicide-resistance factors over the 12-month period.

There was no evidence to suggest that workshop information on the percentage of ryegrass control for different control measures influenced grower perceptions. When location-specific factors influence practice efficacy, the level of control achieved by IWM will be highly variable. As hypothesized, in these circumstances, direct observation of neighboring users' efficacy will have a much greater influence on perceptions than more 'remote' forms of extension information. Such research-based information also may have been discounted because of grower concerns about differences in efficacy between paddock and field-trial research conditions.

The perceived economic value of some practices was positively influenced by targeted information presented during the workshops. In the case of high seed rates, the information suggested that the practice should not be devalued due to the risk of reduced yield and grain quality in drier years. Information on the double-knockdown treatment highlighted its potential value in slowing the development of glyphosate resistance. Consistent with the adoption model for IWM practices (Llewellyn et al., 2007), increasing the perceived value of a practice resulted in an increase in intended adoption.

Providing information on benefits other than percentage of weed control may be a relatively effective approach to encouraging adoption, since the workshop was shown to influence the perceived economic value of some treatments even though the perceived control percentage was not influenced. Hence, the results suggest that extension should target economic factors other than just resistance management. This argument is supported by the relatively high use of practices that provide lower weed control but offer other benefits. In essence, the results suggest that information on the broader economics of IWM practice use within the farming system may have the greatest impact on adoption.

It should be noted that although statistically significant effects of extension were identified in this study, the indicators of the proportion of variance explained by the models are often low. It also needs to be recognized that a minority of growers who can be broadly classified as information-seekers are most likely to be the voluntary participants in events like the one described here. Broadening the impact of such intensive extension events requires diffusion of information from participants to non-participants or greater participation.

Evidently, the workshop resulted in some changes in intended practice use, although it is recognized that stated intentions do not necessarily translate into actual behavior, as indicated in Table 4. The data show a significant large change in wheat seeding rates and evidence of a positive influence on the intention to adopt double knockdown. So, although the diffusion process for IWM practices has generally advanced beyond the early period in which extension is expected to have the greatest influence (Feder & Umali, 1993; Marsh, Pannell, & Lindner, 2000), a single well-targeted, information-based extension event has been shown to improve grower knowledge and to influence adoption intentions.

Conclusion

A range of integrated weed management practices have been promoted in Australia in order to improve the management of HR weeds. An experiment was conducted to determine the influence of an extension workshop on grower perceptions of—and intentions to adopt—IWM practices. The analysis accounted for prior perceptions, prior adoption intentions, and other information sources. Opportunities for more informed herbicide-resistance management by influencing perceptions relating to both the IWM practices and the herbicide resource were demonstrated. The results are encouraging for those developing extension programs aimed at HR management.

Extension events can have a greater impact on adoption decisions when extension agents are able to (a) identify those perceptions that are particularly influential in the adoption decision and (b) recognize which of these perceptions can be most influenced by information. The greatest influence on grower perceptions will occur where information can be delivered with a high degree of certainty and credibility to a population holding prior perceptions that were inconsistent with the information being presented. If the targeted perceptions are associated with the adoption decision, the approach allows quantitative measures of learning to be linked to an expected adoption impact.

As the adoption decision for herbicide-resistance management and prevention depends on perceptions relating not only to weed-management practices but also the herbicide resource, there can be several opportunities for impact through targeted extension. There is clearly a role for targeted extension in influencing grower perceptions and herbicide-resistance management decisions.

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