497

AgBioForum
THE JOURNAL OF AGROBIOTECHNOLOGY MANAGEMENT & ECONOMICS

Volume 12 // Number 3 & 4 // Article 16

Back Issues | Index

PRINTABLE PDF | COMMENT ON THIS ARTICLE | ISSUE CONTENTS | PREVIOUS ARTICLE | NEXT ARTICLE

Perceived Consequences of Herbicide-Tolerant and Insect-Resistant Crops on Integrated Pest Management Strategies in the Western United States: Results of an Online Survey

Judy Harrington, Patrick F. Byrne, Frank B. Peairs, Scott J. Nissen, and Philip Westra
Colorado State University

Peter C. Ellsworth and Al Fournier
University of Arizona

Carol A. Mallory-Smith
Oregon State University

Robert S. Zemetra
University of Idaho

W. Brien Henry
USDA-ARS, Central Great Plains Research Station

We conducted an online survey to assess the potential effects of herbicide-tolerant (HT) and insect-resistant (IR) crops on integrated pest management (IPM) practices in the Western United States For HT crops, participants perceived a decrease in several IPM practices, including crop and herbicide rotations and the combined use of multiple weed control strategies. The most serious potential consequences were considered to be a shift in weed species composition and development of herbicide-resistant weeds. For IR crops, respondents perceived a beneficial reduction in application of both broad-spectrum and selective insecticides. The most significant issues for IR crops were believed to be potential development of target pest resistance and difficulties with management of insect refuges. The survey results support the need for continued emphasis on comprehensive strategies in IPM education programs to prolong the usefulness of HT and IR crops.

Key words: genetically-engineered crops, herbicide tolerance, insect resistance, integrated pest management, IPM, survey.

Introduction

Herbicide-tolerant (HT) and/or insect-resistant (IR) cultivars have been commercialized for several important crops in the Western United States, including wheat, corn, cotton, alfalfa, canola, and sunflower. HT and IR cultivars have the potential to provide important benefits to growers, consumers, and the environment, including increased profitability (Fernandez-Cornejo & Caswell, 2006; Sankula, 2006; Traxler & Falck-Zepeda, 1999), reduced pesticide use

Search

In This Article

(Cattaneo et al., 2006; Fernandez-Cornejo & Caswell, 2006; Sankula, 2006; Wossink & Denaux, 2006), and lower amounts of naturally occurring mycotoxins in food (Wu, 2006). Whether developed through genetic engineering or conventional techniques, these crops also present significant concerns for sustainable pest management. These concerns include the potential for pesticide resistance to develop in target pest populations (Culpepper et al., 2006; Owen & Zelaya, 2005; Sandermann, 2006), gene flow to neighboring crops of the same species or to wild relatives (Gaines et al., 2007; Hall, Topinka, Huffman, Davis, & Good, 2000; Hanson et al., 2005), and negative effects on non-target organisms (Zangerl et al., 2001).

The development of HT cultivars has resulted in a major change in the profile of agricultural chemical use in the United States. For example, in 1997 the chemical most widely used on cotton acreage was the herbicide trifluralin, which was applied on 59% of the cotton crop area. Glyphosate, applied on 14% of the cotton acreage that year, did not rank among the top five chemicals for cotton (US Department of Agriculture National Agricultural Statistics Service [USDA NASS], 1998). By 2007, glyphosate had become the top-ranked chemical used on cotton, applied to 85% of the cotton acreage, while trifluralin had dropped to 5th place with applications on 29% of the crop area (USDA NASS, 2008). Similar changes in usage profiles have been seen in other crops. The large increase in glyphosate use coincided with increased planting of glyphosate-resistant cultivars (Sankula, 2006).

The documentation of glyphosate-resistant biotypes in 15 plant species to date worldwide—including nine in the United States (Heap, 2009)—illustrates the potential of plants to develop resistance under strong selection pressure.

An integrated-pest-management (IPM) strategy is a coordinated approach to the deployment of pest-management practices. Although the use of a single management tactic may be successful in the short term, often the tactic will fail over the long term, especially if it can be overcome by a change in the frequency of a single gene in the pest population (Pedigo & Rice, 2006). A pest is less likely to overcome the destructive influences of several tactics used in concert. IPM coordinates multiple complementary approaches to avoid excessive reliance on a single practice, thus extending the length of time over which practices are effective. In addition to offering sustainability, pest management with several integrated tactics often results in better environmental stewardship. When pesticides are an important component in the program, the addition of other tactics reduces the frequency of pesticide application and the burden of potentially harmful residues in the environment (Pedigo & Rice, 2006). Besides pesticide applications, IPM control methods may include pest-resistant cultivars, pest monitoring, biological control methods, and cultural practices. As with single-tactic approaches involving herbicides, exclusive use of a pest-resistant cultivar may lead to eventual failure of control. Several authors (e.g., Bates, Zhao, Roush, & Shelton, 2005; Dyer, 1994;

Knezevic, 2002) have pointed out that over-reliance on HT or IR crops to control insects and weeds will shorten the effective life of these cultivars. They advocate using these crops within the context of an IPM program that also includes biological or cultural control methods.

A survey is one method for evaluating adoption of agronomic practices and perceptions about those practices. Surveys on pesticide use in potatoes (Dillard, Wicks, & Philp, 1993) and cotton (Charles, 1991) in Australia, grower perceptions about weed problems in Indiana (Gibson, Johnson, & Hillger, 2005; Gibson, Hillger, & Johnson, 2006), perceptions about HT cultivars in Australia (Llewellyn, Lindner, Pannell, & Powles, 2002), and grower views of tillage, weed pressure, and herbicide use in the Midwestern United States (Givens et al., 2009a, 2009b; Kruger et al., 2009; Shaw et al., 2009) are examples of surveys used to document practices and perceptions.

To assess the possible consequences of HT and IR cultivars on IPM strategies in the Western United States, we conducted an online survey in 2005. Our objectives were to (1) assess perceived changes in farming practices due to HT and IR cultivars, (2) solicit opinions on the benefits and risks of several HT and IR crops, (3) gather input on the seriousness of several potential outcomes of over-reliance on HT and IR crops, and (4) determine the need for additional educational efforts on IPM issues related to HT and IR crops in the region.

Methods

We developed a survey targeted to agricultural professionals, i.e., growers, researchers, educators, consultants, and administrators, in both the public and private sectors. The survey was approved by the Colorado State University Human Research committee and was conducted online from April 11 to October 12, 2005. The survey's initial section gathered information about the participant's home state, occupation, and employer. Participants were questioned about their experience with HT and IR cultivars and their perceptions of important issues and potential risks and benefits associated with these cultivars in the Western United States. Participants were asked whether sufficient information was available regarding IPM practices in HT and IR crops, and were requested to rate their preferences for receiving this information. The second section focused on HT cultivars and the third section on IR cultivars. Participants who had no experience with HT cultivars were offered the option of skipping the second section and proceeding directly to the section on IR crops. Participants were required to choose among a limited set of structured responses to most questions, but they were given frequent opportunities to type unstructured responses into a text box. Participants were recruited through announcements on university websites and newsletters, posters at scientific meetings, and email messages to list-serves of agricultural professionals. Targeted states were Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. We also received responses from participants in Kansas, Missouri, Nebraska, North Dakota, and Oklahoma. All responses were used in our summaries and analysis.

For both the HT and IR sections of the survey, participants indicated the crops with which they had experience and rated the usefulness of existing cultivars and of several crops that were not yet available at the time of the survey but may be released in the next few years. Respondents then estimated the changes in frequency of several farming practices, evaluated the seriousness of certain potential consequences relevant to either HT or IR cultivars, and rated the potential for each crop to cause such consequences in Western US farming systems. For existing cultivars, these ratings could be based on both experience and expectations, while for hypothetical crops, the ratings would of necessity be based only on expectations. Data were analyzed in the SAS 9.1 statistical software program (SAS, 2004) using t-tests for survey questions that asked for numerical ratings and using chi-square tests for questions that asked for yes/no responses.

The crops included in the survey are listed in Tables 1 to 3. Table 1 provides the total area planted to each crop in the Western United States in 2006 and estimates of percent of total area planted to HT and IR cultivars. Specific types of HT and IR cultivars for each crop are listed in Tables 2 and 3, respectively.

Table 1. Total area of selected crops in the Western United States (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) and estimated proportions that are HT or IR, whether through genetic engineering or conventional breeding.

Crop	Total area, 2006 (1,000 ha)	Estimated percent HT	Estimated percent IR
Alfalfa, new seeding, *Medicago sativa*	288	NA	NA[a]
Canola, *Brassica napus*	8	>90[b]	NC
Corn, *Zea mays*	971	61	20[c]
Cotton, *Gossypium hirsutum*	360	53	26
Sorghum, *Sorghum bicolor*	151	NC	>90
Sunflower, *Helianthus annuus*	57	15	NC
Wheat, *Triticum aestivum*	5,496	4	11[d]

Notes. Information is primarily from the National Agricultural Statistics Service (http://www.nass.usda.gov/) and Sankula (2006), supplemented by estimates from crop scientists in the region.

NA=data not available; NC=not currently commercialized.

[a] Most current US alfalfa varieties are rated either resistant or highly resistant to aphids (National Alfalfa & Forage Alliance, 2006).

[b] Based on percentage for North Dakota, which accounts for 92% of total US canola acreage.

[c] Does not include Herculex brand hybrids.

[d] Includes Russian wheat aphid-resistant, sawfly-resistant, and Hessian fly-resistant varieties.

Table 2. Existing and potential HT crops included in the survey.

Crop	Trait	Source of trait[a]	First approved for commercial planting in the United States
Alfalfa	Glyphosate tolerant[b]	GE	2005
Canola	Glyphosate tolerant	GE	1999
	Glufosinate tolerant[c]	GE	1995
	Imidazolinone tolerant[d]	IM	1995[e]
Corn	Glyphosate tolerant	GE	1997
	Glufosinate tolerant	GE	1995
	Imidazolinone tolerant	IM	1992[e]
Cotton	Glyphosate tolerant	GE	1995
	Bromoxynil tolerant[f]	GE	1994
Sugar beet	Glyphosate tolerant	GE	1998
Sunflower	Imidazolinone tolerant	IM	2003[e]
Wheat	Glyphosate tolerant	GE	Partial approval[g]
	Imidazolinone tolerant	IM	2001

Note. [a] GE, genetically engineered; IM, induced mutation.
[b] Trade name: Roundup Ready®
[c] Trade name: LibertyLink™
[d] Trade name: Clearfield®
[e] Formal approval not required for non-GE varieties; date is the year of commercial release.
[f] Trade name: BXN
[g] Approved by the Food and Drug Administration for food/feed; application later withdrawn before decisions on environmental safety were made by the US Department of Agriculture and the Environmental Protection Agency.

Table 3. Existing and potential IR crops included in the survey.

Crop	Trait	Source of trait[a]	First approved for commercial planting in the US
Alfalfa	Aphid resistance	C	1957[b]
Corn	Single Bt gene for corn borer control	GE	1995
	Single Bt gene for corn rootworm control	GE	2003
	Bt genes for both corn borer and corn rootworm control	GE	2005
Cotton	Bt *Cry1Ac*-based resistance (e.g., Bollgard)	GE	1995
	Bt *Cry2Ab* + *Cry1Ac*-based resistance (e.g., Bollgard II)	GE	2002
	Bt *Cry1F* + *Cry1Ac*-based resistance (e.g., Widestrike)	GE	2004
	VIPcot-based resistance	GE	2005[c]
	Bt stacked with herbicide tolerance genes	GE	1997[d]
Sorghum	Greenbug resistance	C	1975[b]
Wheat	Hessian fly resistance	C	1942[b]
	Russian wheat aphid resistance	C	1994[b]

Note. [a] C, conventional crossing with a naturally occurring resistance source; GE, genetically engineered.
[b] Formal approval not required for non-GE products; date is the year of commercial release.
[c] Approved for food/feed only; not yet approved for environmental safety.
[d] Formal approval not required for combinations of approved GE products unless both are insect resistant products.

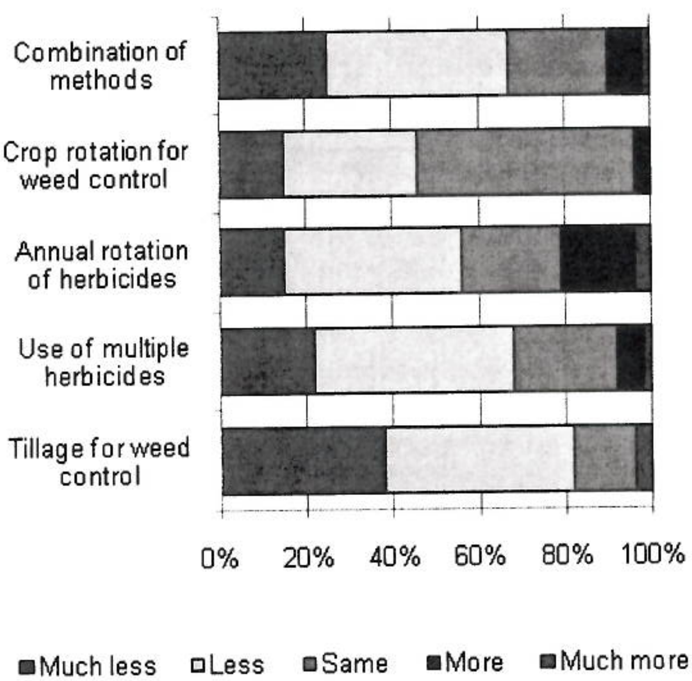
Results and Discussion

Of the 54 self-selecting participants, 32 (59%) were from the public sector and 20 (37%) from the private sector, with two (4%) participants not responding to the question. Sixteen states in the Western United States and adjoining regions were represented. Occupations of the participants included professor, research scientist, extension agent, consulting weed scientist, botanist, and biotechnology company representative. The participants were mostly professionals in agricultural research, education, and production.

Perceived Changes in Farming Practices Due to HT and IR Cultivars

The weed-control practice thought to have changed the most was tillage; more than 80% of the respondents felt there was less or much less tillage in HT crops compared to conventional crops (Figure 1). This is not surprising because reduced tillage is one of the major benefits of HT crops, leading to enhanced soil and water conservation and reduced fuel consumption. Our results agree with those of Givens et al. (2009b), who found a large shift toward low-till or no-till systems among Midwestern US growers who adopted glyphosate-resistant crops.

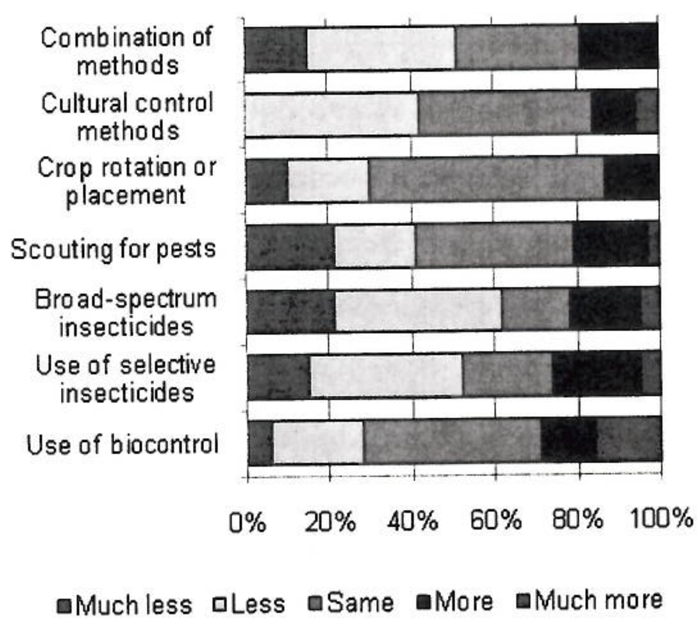
Figure 1. Perceived changes in frequency of farming practices in HT crops compared to conventional crops. The colored segments of each bar indicate the percent of respondents who chose each answer (out of the 53 total respondents).



Multiple herbicide use was also rated as changing substantially with the adoption of HT crops. More than 60% of those surveyed believed there was a reduction in the use of multiple herbicides. Replacement of multiple products with a single broad-spectrum product like glyphosate simplifies weed management, making it easier and often more cost-effective, a significant advantage for growers. Use of a single herbicide like glyphosate may also reduce the use of other products that have more detrimental effects on the environment. However, overuse of a single product may contribute to selection for herbicide resistance and thus runs counter to an IPM strategy. Also worrisome are the perceived reductions in herbicide rotation (54% reported less or much less use of this practice), crop rotation (46% reported less or much less use), and a combination of methods (67% reported less or much less use). These last three practices are potential contributors to an integrated-weed-management program, and their reduced frequency causes concern about the potential for herbicide-resistant weeds to develop. Results of our survey in regard to weed-management practices are consistent with the findings of a survey of Midwestern and Southern US farmers showing lack of awareness of herbicide-resistance-management strategies (Johnson et al., 2009).

Changes in insect pest-management practices generally did not indicate a move away from IPM approaches (Figure 2). The majority of participants perceived similar or increased use of biological control, scouting, crop rotation, and other cultural controls. The majority also perceived a reduction in broad-spectrum insecticide use, and roughly half believed there was a reduction in selective insecticide use as well. However, 50% of the participants perceived a reduction in the use of combinations of insect-management methods, which may reflect a tendency for over-reliance on IR crops.

Figure 2. Perceived changes in frequency of farming practices in IR crops compared to conventional crops. The colored segments of each bar indicate the percent of respondents who chose each answer (out of the 32-34 respondents for each practice).



Benefits and Risks of HT and IR Crops

Herbicide-tolerant crops fell into three general categories with regard to their perceived benefits and risks: those with high usefulness and low potential to cause problems, those with moderate usefulness and moderate potential to cause problems, and those with lower usefulness and higher potential to cause problems. Table 4 shows a broad trend of increasing usefulness being associated with declining potential to cause problems. The four Roundup Ready crops with the highest usefulness ratings—sugar beet, cotton, canola, and corn—also had potential problem-causing ratings at least one point lower than the corresponding usefulness rating. Thus, the advantages of these crops were viewed as being substantially greater than their disadvantages. Clearfield sunflower, Clearfield wheat, Roundup Ready alfalfa, and Roundup Ready spring wheat were rated moderate in both usefulness and potential for problems, with a difference between the corresponding ratings of 0 to 1 point. Roundup Ready winter wheat received the lowest score for usefulness and the highest rating for problem-causing potential, indicating that concerns with the technology outweighed the perceived benefits.

Table 4. Ratings of existing and potential HT crops for usefulness and potential problems

Crop	Usefulness	Potential to cause problems	Difference between ratings
Roundup Ready sugar beet	4.40 (40)	2.36 (39)	2.04
Roundup Ready cotton	4.23 (31)	2.42 (31)	1.81
Roundup Ready canola	4.23 (30)	3.00 (36)	1.23
Roundup Ready corn	4.13 (49)	2.86 (51)	1.27
Clearfield sunflower	4.02 (30)	3.22 (36)	0.80
Clearfield wheat	3.55 (38)	3.40 (43)	0.15
Roundup Ready alfalfa	3.37 (52)	2.88 (50)	0.49
Roundup Ready spring wheat	2.97 (39)	3.23 (44)	-0.26
Roundup Ready winter wheat	2.63 (43)	3.87 (47)	-1.24

Note. Usefulness ratings range from 5 (very useful) to 1 (not useful). Ratings range from 5 (very serious potential) to 1 (no serious potential). Number of respondents is given in parentheses after each rating.

All instances of IR crops were rated as at least moderately useful (Table 5). Transgenic IR crops tended to have higher usefulness ratings than conventional IR crops, reflecting the higher resistance levels typical of transgenic crops. In every case, the rating for problem-causing potential was at least one point lower than the corresponding usefulness rating. No differences were noted between transgenic and conventional IR crops regarding their potential to cause problems.

Table 5. Perceptions of usefulness and potential problems for existing and

potential IR crops.

Crop	Usefulness	Potential to cause problems	Difference between ratings
Bt corn for corn rootworm	4.30 (30)	2.24 (33)	2.06
Bt corn stacked for corn borer and corn rootworm	4.15 (27)	2.35 (31)	1.80
Bt *Cry2Ab* cotton	4.15 (13)	1.85 (13)	2.30
Bt cotton stacked with HT	4.14 (14)	2.00 (16)	2.14
Bt corn for corn borer	4.03 (32)	2.27 (33)	1.76
Bt *Cry1Ac* cotton	3.92 (12)	2.29 (14)	1.63
Russian wheat aphid resistant wheat	3.91 (23)	2.46 (26)	1.45
Aphid resistant alfalfa	3.76 (17)	1.95 (19)	1.81
Hessian fly resistant wheat	3.71 (17)	1.83 (18)	1.88
Greenbug resistant sorghum	3.61 (18)	2.19 (16)	1.42
Bt *Cry1F* cotton	3.40 (10)	2.00 (11)	1.40
VIP cotton	3.22 (9)	2.15 (13)	1.07

Note. Usefulness ratings range from 5 (very useful) to 1 (not useful). Ratings range from 5 (very serious potential) to 1 (no serious potential). Number of respondents is given in parentheses after each rating.

Seriousness of Several Potential Outcomes of Over-reliance on HT and IR Crops

For HT crops, the most serious concerns were considered to be shifts in weed-species composition and development of herbicide-resistant weeds due to repeated applications of a single herbicide (Table 6). If either of these does occur, there may be IPM consequences because growers may have to increase herbicide rates or application frequency or switch to another product that may be more detrimental to the environment. Controlling volunteer plants was also rated as a moderately serious management issue. This concern would apply specifically to situations where a given herbicide is designed for use with an HT crop and is also an important part of a volunteer management program, for example, Roundup Ready winter wheat. Topics that rated an intermediate level of concern (ratings of 2.64 to 3.00) included gene flow to the same crop or to wild relatives, and a series of issues related to cultivar availability: the perceived presence of fewer cultivars on the market, poorer adaptation of those cultivars to local conditions, or genetic vulnerability due to the presence of the same transgenes in a large percentage of cultivars (Table 6). Lower ratings (<2.50) were given to changes in disease and insect problems due to HT crops and to effects on other organisms in the agricultural ecosystem.

Table 6. Seriousness of potential consequences of HT crops as perceived by survey participants.

Topics surveyed for HT cultivars	Average rating
Shifts in weed species composition	4.04 (53)
Development of herbicide tolerance in weed populations through selection pressure	3.98 (53)

More difficult to manage volunteers	3.60 (53)
Fewer cultivars available in the marketplace	3.00 (53)
Gene flow to other fields of the same crop	2.86 (50)
Gene flow to wild populations of related plants	2.84 (51)
Genetic vulnerability due to presence of the same genes in a large proportion of cultivars of a crop	2.79 (52)
Poorer adaptation of cultivars to your local production practices	2.64 (53)
Negative changes in disease or insect problems due to changes in cultivation practices	2.45 (42)
Effects on soil ecosystems, e.g. microbial composition, due to repeated use of the same herbicide	2.28 (47)
Less food available for beneficial insects/arthropods	2.08 (49)
Negative changes in disease or insect problems due to effects of the herbicide	2.03 (39)
Less food available for birds or other wildlife	2.02 (49)

Note. Ratings range from 5 (very serious) to 1 (not serious). Number of respondents is given in parentheses after each rating.

Seriousness ratings for several potential consequences of HT crops varied significantly ($P<0.05$) depending on whether the respondents perceived that there was or was not enough information available on these crops (Table 7). The greatest discrepancies concerned perceptions of the seriousness of gene flow. From our results we cannot determine the causal factor for these differences. Those who rated a problem more serious may have been less aware that information was available, or conversely, those who considered a problem to be a less serious concern may have been satisfied with the available information. Whether respondents felt there was or was not sufficient information available about IR crops, they perceived the consequences to have the same level of seriousness.

Table 7. Differences in perceptions of seriousness among respondents who said there was/was not enough information available on HT crops.

	Average rating		
Topic	**Enough information available**	**Not enough information available**	***P*-value**
Seriousness of crop-to-crop gene flow	1.92	2.95	0.0005
Seriousness of crop-to-wild gene flow	1.82	2.98	0.0005
Seriousness of soil ecosystem effects	1.47	2.12	0.0227
Seriousness of reduction in food for insects	1.28	1.97	0.0145
Seriousness of genetic vulnerability due to many cultivars having the same genes	1.83	2.70	0.0080
Seriousness of reduction in number of cultivars on the market	1.92	2.96	0.0075

Note. Ratings range from 5 (very serious) to 1 (not serious).

The greatest concerns about the potential consequences of IR crops were the development of resistance in target pests and difficulties associated with refuge management (Table 8). Some insect pests targeted by transgenic IR crops (e.g., corn rootworm) have long histories of developing resistance to insecticides and other management tactics, which may explain similar concerns for the control strategy deployed in current transgenic IR cultivars. Regulatory oversight of IR crops is new with the advent of transgenic crops. Past experience indicating less-than-optimal compliance with pesticide regulations may provide some basis for concerns about compliance with refuge requirements. A survey of US corn growers showed that compliance with such requirements for Bt corn was only 71% in 2000 (Agricultural Biotechnology Stewardship Technical Committee [ABSTC], 2001). After the implementation of stricter enforcement measures and a widespread informational program, compliance rose to about 95% in 2004 and 2005, but some farmers are still unaware that a refuge is required and farmers in the South lag behind their northern counterparts in compliance (ABSTC, 2005). We know of no comparable figures for the Western United States. Because refuge requirements for corn hybrids with combined resistance to corn borer and corn rootworm can be more complicated than requirements for hybrids with corn borer resistance alone (Monsanto, 2009), full compliance for the "stacked" hybrids may be more difficult to attain.

Table 8. Seriousness of potential consequences of IR crops as perceived by participants.

Topics surveyed for IR cultivars	Average rating
Development of resistance in target pests	3.68 (38)
Difficulties with management of insect refuges, including non-compliance	3.21 (34)
More complicated resistance management due to stacked insect resistance genes in the same variety	2.61 (31)
Fewer cultivars available in the marketplace	2.60 (35)
Poorer adaptation of cultivars to local production practices	2.58 (36)
Genetic vulnerability due to presence of the same genes in a large proportion of cultivars of a crop	2.47 (34)
Negative effects on beneficial or non-target insects	2.25 (36)
Gene flow to other fields of the same crop	2.24 (34)
Negative changes in disease or insect problems due to changes in cultivation practices	2.24 (33)
Gene flow to wild populations of related plants	2.06 (34)
Effects on soil ecosystems, e.g., microbial composition, due to residue of resistance compounds leaking into soil	1.91 (32)
Less food available for birds or other wildlife	1.85 (34)
Less food available for beneficial insects/arthropods	1.76 (33)

Note. Ratings range from 5 (very serious) to 1 (not serious). Number of respondents is given in parentheses after each rating.

Need for Additional Educational Efforts on IPM Issues Related to HT and IR Crops

When there was a significant difference between groups, respondents who worked in the private sector were more likely to consider potential problems less serious than respondents who worked in the public sector (Table 9). For example, private-sector employees rated the development of herbicide resistance less serious than did public sector employees (2.96 versus 3.96 on a 5-point scale). Regarding adequacy of available information, respondents from the private sector were significantly more likely to say there was enough information available on HT and IR crops than respondents in the public sector (70% for private sector, 59% for public sector, $P<0.05$). One factor that might contribute to this difference in perception is that public-sector employees may not be fully aware of the information provided to growers at the time seed is purchased. An example of this type of information is Monsanto's Technology Use Guide (Monsanto, 2009).

Table 9. Differences in perceptions among respondents employed in the private and public sectors.

Topic	Average rating by private sector respondents	Average rating by public sector respondents	*P*-value
Seriousness of development of herbicide resistance	2.93	3.96	0.0023
Seriousness of crop-to-crop gene flow from HT crops	1.64	2.75	0.0076
Seriousness of crop-to-wild gene flow from HT crops	1.76	2.67	0.0152

Note. Ratings range from 5 (very serious) 1 (not serious).

Respondents in both sectors mentioned fact sheets as a preferred method of receiving information more often than they mentioned any other method of information delivery (Table 10). Close behind fact sheets were workshops and web sites run by universities. Information delivery at the point of seed purchase was less popular, while web sites run by companies and e-mail were the least popular methods of receiving information. Respondents could check more than one delivery method as preferred, so there were more total votes than respondents. Seventy percent of respondents felt there was sufficient information available on IR crops, but only 50% felt information on HT crops was sufficient.

Table 10. Preferences for delivery of information.

Preferred way to receive information	Public sector employees	Private sector employees	Combined public and private sectors
Fact sheets	28 (88%)	9 (45%)	37 (71%)
Workshops	21 (66%)	5 (25%)	26 (50%)
Web sites run by universities	18 (56%)	7 (35%)	25 (48%)
Seed purchase	11 (34%)	7 (35%)	18 (35%)
Web sites run by companies	7 (22%)	6 (30%)	13 (25%)
E-mail	5 (16%)	4 (20%)	9 (17%)

Total votes	90	38	128
Total respondents	32	20	52 (plus 2 not responding to the question on sector)

Note. Numbers in parentheses=percentage of respondents giving that answer.

Conclusions and Recommendations

More than half of the survey participants perceived an overall reduction in IPM practices resulting from the adoption of HT crops. Over-reliance on any one pest control method may cut short its effective life and runs counter to the philosophy of using a multi-faceted IPM approach whenever possible. The sustainability of HT technology may depend on concerted efforts to maintain an array of weed-management strategies despite the appeal of HT crops as a simple solution over the short term. The perception that weed-management approaches are narrowing suggests an opportunity to reinforce the importance of IPM approaches when using HT crops to ensure profitable and sustainable farming practices. Recent educational efforts—such as the Resistance Management set of online courses sponsored by the National Corn Growers Association (http://ncga.adayana.com/)—may have achieved improvements in grower practices since our survey was completed.

Insect-resistant crops were viewed as generally compatible with current IPM approaches. Additionally, IR crops were perceived to be effective insect management tools with relatively low potential for causing additional management problems. Concerns with IR crops were associated with the related topics of resistance management and refuge management, including non-compliance issues. Educational programming should emphasize the importance of compliance with refuge requirements in slowing the development of resistance, thereby preserving the effectiveness of IR crops.

References

Agricultural Biotechnology Stewardship Technical Committee (ABSTC). (2001, January). *Bt corn insect resistance management survey 2000 growing season.* Available on the World Wide Web: http://www.biotech-info.net/bt_corn_survey_2000.pdf.

ABSTC. (2005). *Insect resistance grower management survey for corn borer-resistant Bt field corn 2004 growing season.* Available on the World Wide Web: http://www.pioneer.com/CMRoot/pioneer/biotech/irm/survey.pdf.

Bates, S.L., Zhao, J.Z., Roush, R.T., & Shelton, A.M. (2005). Insect resistance management in GM crops: past, present and future. *Nature Biotechnology, 23*, 57-62.

Cattaneo, M.G., Yafuso, C., Schmidt, C., Huang, C.Y., Rahman, M., Olson, C., et al.

(2006). Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield. *Proceedings of the National Academy of Sciences USA, 103*, 7571-7576.

Charles, G.W. (1991). A grower survey of weeds and herbicide use in the New South Wales cotton industry. *Australian Journal of Experimental Agriculture, 31*, 387-392.

Culpepper, A.S., Grey, T.L., Vencill, W.K., Kichler, J.M., Webster, T.M., Brown, S.M., et al. (2006). Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. *Weed Science, 54*, 620-626.

Dillard, H.R., Wicks, T.J., & Philp, B. (1993). A grower survey of diseases, invertebrate pests, and pesticide use on potatoes grown in South Australia. *Australian Journal of Experimental Agriculture, 33*, 653-661.

Dyer, W. (1994). Resistance to glyphosate. In S.B. Powles & J.A.M. Holtum (Eds.), *Herbicide resistance in plants: Biology and biochemistry* (pp. 229-141). Boca Raton, FL: Lewis Publishers.

Fernandez-Cornejo, J., & Caswell, M. (2006, April). *The first decade of genetically engineered crops in the United States* (Economic Information Bulletin Number 11). Washington, DC: United States Department of Agriculture Economic Research Service (USDA ERS). Available on the World Wide Web: http://www.ers.usda.gov/publications/EIB11/.

Gaines, T.A., Byrne, P.F., Westra, P., Nissen, S.J., Henry, W.B., Shaner, D.L., & Chapman, P.L. (2007). An empirically derived model of field-scale gene flow in winter wheat. *Crop Science, 47*, 2308-2316.

Gibson, K.D., Johnson, W.G., & Hillger, D.E. (2005). Farmer perceptions of problematic corn and soybean weeds in Indiana. *Weed Technology, 19*, 1065-1070.

Gibson, K.D., Hillger, D.E., & Johnson, W.G. (2006). Farmer perceptions of weed problems in corn and soybean rotation systems. *Weed Technology, 20*,751-755.

Givens, W.A., Shaw, D.R., Johnson, W.G., Weller, S.C., Young, B.G., Wilson, R.G., et al. (2009a). A grower survey of herbicide use patterns in glyphosate-resistant cropping systems. *Weed Technology, 23*,156-161.

Givens, W.A., Shaw, D.R., Kruger, G.R., Johnson, W.G., Weller, S.C., Young, B.G., et al. (2009b). Survey of tillage trends following the adoption of glyphosate-resistant crops. *Weed Technology, 23*, 150-155.

Hall, L., Topinka, K., Huffman, J., Davis, L., & Good, A. (2000). Pollen flow between herbicide-resistant *Brassica napus* is the cause of multiple-resistant *B. napus* volunteers. *Weed Science, 48*, 688-694.

Hanson, B.D., Mallory-Smith, C.A., Price, W.J., Shafii, B., Thill, D.C., & Zemetra, R.S. (2005). Interspecific hybridization: Potential for movement of herbicide resistance from wheat to jointed goatgrass (*Aegilops cylindrica*). *Weed Technology, 19*, 674-682.

Heap, I. (2009). International survey of herbicide resistant weeds. Available on the World Wide Web: http://www.weedscience.org.

Johnson, W.G., Owen, M.D.K., Kruger, G.R., Young, B.G., Shaw, D.R., Wilson, R.G., et al. (2009). U.S. farmer awareness of glyphosate-resistant weeds and resistant management strategies. *Weed Technology, 23*, 308-312.

Knezevic, S.Z. (2002). *Use of herbicide tolerant crops as a component of an integrated weed management program* (Pub. no. G02-1484-A). Lincoln, NE: Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.

Kruger, G.R., Johnson, W.G., Weller, S.C., Owen, M.D.K., Shaw, D.R., Wilcut, J.W., et al. (2009). U.S. grower views on problematic weeds and changes in weed pressure in glyphosate-resistant corn, cotton, and soybean cropping systems. *Weed Technology, 23*, 162-166.

Llewellyn, R.S., Lindner, R.K., Pannell, D.J., & Powles, S.B. (2002). Resistance and the herbicide resource: perceptions of Western Australian grain growers. *Crop Protection, 21*, 1067-1075.

Monsanto. (2009). IRM guide: Corn- and cotton-growing areas. St. Louis, MO: Author. Available on the World Wide Web: http://www.monsanto.com/monsanto/ag_products/pdf/stewardship/2009_irm_guide.pdf.

National Alfalfa & Forage Alliance. (2006). *Winter survival, fall dormancy, and pest resistance ratings for alfalfa varieties* (2006/2007 edition). Kennewick, WA: Author. Available on the World Wide Web: http://www.alfalfa.org/pdf/2006%20Final%20Variety%20Leaflet.pdf.

Owen, M.D.K., & Zelaya, I.A. (2005). Herbicide-resistant crops and weed resistance to herbicides. *Pest Management Science, 61*, 301-311.

Pedigo, L.P., & Rice, M.E. (2006). *Entomology and pest management* (5th ed.). Upper Saddle River, NJ: Pearson Education, Inc.

Sandermann, H. (2006). Plant biotechnology: Ecological case studies on herbicide resistance. *Trends in Plant*

Sankula, S. (2006). *Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2005*. Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: http://www.ncfap.org/documents/2005biotechimpacts-finalversion.pdf.

SAS. (2004). *SAS procedures guide, version 9.1*. Cary, NC: SAS Institute, Inc.

Shaw, D.R., Givens, W.A., Farno, L.A., Gerard, P.D., Jordan, D., Johnson, W.G., et al. (2009). Using a grower survey to assess the benefits and challenges of glyphosate-resistant cropping systems for weed management in U.S. corn, cotton, and soybean. *Weed Technology*, *23*, 134-149.

Traxler, G., & Falck-Zepeda, J. (1999). The distribution of benefits from the introduction of transgenic cotton varieties. *AgBioForum*, *2*(2), 94-98. Available on the World Wide Web: http://www.agbioforum.org.

US Department of Agriculture National Agricultural Statistics Service (USDA NASS). (1998, May). *Agricultural chemical usage, 1997 field crops summary*. Washington, DC: Author. Available on the World Wide Web; http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC//1990s/1998/AgriChemUsFC-05-20-1998.pdf.

USDA NASS. (2008, May). *Agricultural chemical usage, 2007 field crops summary*. Washington, DC: Author. Available on the World Wide Web: http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC//2000s/2008/AgriChemUsFC-05-21-2008.pdf.

Wossink, A., & Denaux, Z.S. (2006). Environmental and cost efficiency of pesticide use in transgenic and conventional cotton production. *Agricultural Systems*, *90*, 312-328.

Wu, F. (2006). Mycotoxin reduction in Bt corn: Potential economic, health, and regulatory impacts. *Transgenic Research*, *15*, 277-289.

Zangerl, A.R., McKenna, D., Wraight, C.L., Carroll, M., Ficarello, P., Warner, R., & Berenbaum, M. (2001). Effects of exposure to event 176 *Bacillus thuringiensis* corn pollen on monarch and black swallowtail caterpillars under field conditions. *Proceedings of the National Academy of Sciences USA*, *98*, 11908-11912.

Acknowledgments

The authors wish to thank those who participated in the survey. We gratefully acknowledge grant funding from USDA's Western Integrated Pest Management

Center (http://www.wrpmc.ucdavis.edu/) to support a work group on this topic.

Suggested citation: Harrington, J., Byrne, P.F., Peairs, F.B., Nissen, S.J., Westra, P., et al. (2009). Perceived consequences of herbicide-tolerant and insect-resistant crops on integrated pest management strategies in the western United States: Results of an online survey. *AgBioForum*, *12*(3&4), 412-421. Available on the World Wide Web: http://www.agbioforum.org.