Western regional work group on IPM consequences of herbicide tolerant (HT) and insect resistant (IR) crops (2004-2007)

Final Report

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I. Executive summary

Herbicide tolerant and insect resistant (HTIR) cultivars continue to be introduced for a growing number of Western crops, including wheat, corn, cotton, canola, sugar beet, sunflower, and alfalfa. Whether developed through genetic engineering or conventional techniques, these crops present important issues for sustainable pest management. These issues include the potential for gene flow to neighboring crops and to wild relatives, shifts in weed species, development of resistance in target pest populations, negative effects on non-target organisms, and changes in recommended pest management practices. Our work group assessed information and research needs regarding IPM practices in the management of HTIR crops.

Accomplishments

- Our Western regional work group, established in 2004, consisted of 11 research and extension professionals who are actively involved in HTIR crops. The group expanded in 2005 with the inclusion of private sector participants who provided additional perspectives on the issues presented by HTIR crops.

- We purchased video conferencing hardware and software for group members and held video conferences with both the full group and smaller subgroups to discuss goals and strategies.

- We established a web site to share information resources on HTIR crops. The site provides easy access to fact sheets, PowerPoint slide sets, news summaries, journal articles, and links to related sites. After initial establishment, the site was migrated to a long-term home and was given a direct URL, http://www.htiripm.colostate.edu. Future site maintenance will be handled by the Department of Soil and Crops Sciences at Colorado State University.

- We surveyed agricultural professionals in the public and private sectors about their perceptions of many issues involving HTIR crops. Results of the survey are available on the HTIR web site. A manuscript describing the results of the survey has been submitted for publication in a research journal.

- We developed a set of priorities for research and information needs, along with strategies for addressing them, based on the survey results and the research and extension knowledge of the collaborators who participated with us on this WRIPM grant project. **See pp. 9-11 for elaboration of these priorities.**

Research priorities

There is insufficient understanding of issues related to herbicide resistance. High adoption rates of HT cultivars and the development of additional HT crops will put increasing evolutionary pressure on weeds, while also enhancing the possibility that volunteers will display resistance to more than one herbicide. Understanding of insect resistance in relation to IR crops is further advanced, but questions remain. We recommend that researchers

- determine whether there is evidence of weed shifts or herbicide resistance in weeds in the Western U.S.
- investigate mechanisms of herbicide resistance.
- explore the frequency and potential impact of introgression of HT or IR genes from crops to wild species.
- develop optimum IPM strategies for sustainable weed control with HT crops.
- determine whether levels of Bt resistance are increasing in corn borers or corn rootworm as a result of the utilization of Bt corn.
- evaluate the biotype composition of Russian wheat aphid and assess the effect this will have on pest management.
- develop best IPM practices for pest control in reduced tillage systems.

Information priorities

There are information gaps for the Western region concerning

- acreage of HT and IR crops being planted.
- specific HT and IR traits that are being utilized.
- reasons for choosing an HT or IR cultivar in a cropping system.
- compliance rates for managing the development of resistance.

We recommend an initiative to compile this information, either by collecting it from growers or by acquiring it from other groups that may already collect it.

Education priorities

Education efforts regarding the importance of IPM practices in HT and IR crops should be increased. Important topics include

- the effects of selection pressure on development of resistance.
- herbicide application rates in relation to resistance development.
- the mechanisms of gene flow from cultivars to wild species.
- cross-commodity information herbicides when multiple crops are impacted.
- equivalencies among products containing glyphosate.

Survey results

Survey participants perceived a decrease in several IPM practices among growers using HT cultivars. Rotation of crops, rotation of herbicides, and the use of a combination of weed control methods all declined. The most serious potential consequences of HT cultivars were considered to be a shift in weed species and development of herbicide-resistant weeds. Several Roundup Ready crops were rated as very useful, despite some potential for negative consequences. However, for Roundup Ready wheat and Roundup Ready alfalfa the problem-causing potential was rated higher than usefulness to growers.

Growers using IR cultivars are using fewer applications of both broad-spectrum and selective insecticides, according to respondents. IPM practices, including the use of biocontrol, scouting for pests, crop rotation or placement, and cultural control, are similar or have increased among growers using IR cultivars. The most serious problems associated with IR cultivars were believed to be the development of resistance in target pests and difficulties with management of insect refuges. All IR crops were rated higher in usefulness than in problem-causing potential, and were perceived to have only low potential for causing problems.

There may be a need for more information on HT crops. There was a significant association between respondents who said available information was insufficient and those who rated HT crops higher for potential to cause problems in the areas of soil ecosystem effect, gene flow to neighboring crops and to wild relatives, and reduction in food for insects. Respondents who felt there was insufficient information on HT crops also gave higher seriousness ratings to the problems of genetic vulnerability and reduction in number cultivars on the market.

Public sector respondents were more likely than respondents from the private sector to consider that HT crops had the potential to cause serious problems in the area of gene flow to both neighboring crops and wild relatives and development of herbicide resistance.

Fact sheets were the most preferred method of receiving information, followed by workshops and university-maintained web sites. Information provided with a seed purchase, company web sites, and e-mail were not considered by most respondents to be preferred methods.

II. List of Participants

Dr. Jack Brown, University of Idaho, associate professor in the Department of Plant, Soil and Entomological Sciences.

Dr. Patrick Byrne, Colorado State University, associate professor in the Department of Soil and Crop Sciences.

Dr. Mark Dahmer, formerly with BASF Corp. in Denver.

Dr. Peter Ellsworth, University of Arizona, IPM specialist in the Department of Entomology.

Dr. Al Fournier, University of Arizona, IPM program manager.

Judy Harrington, Colorado State University, research associate in the Department of Soil and Crop Sciences.

Dr. Brien Henry, United States Department of Agriculture-Agricultural Research Service, weed scientist in Akron, Colorado.

Dr. Carol Mallory-Smith, Oregon State University, professor in the Department of Crop and Soil Sciences.

Dr. Scott Nissen, Colorado State University, associate professor in the Department of Bioagricultural Sciences and Pest Management.

Dr. Frank Peairs, Colorado State University, professor of Entomology in the Department of Bioagricultural Sciences and Pest Management.

Dr. Todd Pester, Monsanto Company, ecologist in Biotechnology Regulatory Affairs, St. Louis, Missouri.

Dr. Oscar Riera-Lizarazu, Oregon State University, associate professor in the Department of Crop and Soil Science.

Dr. Phil Westra, Colorado State University, professor in the Department of Bioagricultural Sciences and Pest Management.

Dr. Robert Zemetra, University of Idaho, professor in the Department of Plant, Soil, and Entomological Sciences.

III. Web site development

A web site to share information resources on HTIR crops was established in 2005 and was gradually enhanced over the subsequent two years. The home page (Fig. 1) lists the principal topics. The site provides easy access to fact sheets, PowerPoint slide sets, news summaries, journal articles, and links to related sites. After initial establishment, the site was migrated to a long-term home and was given a direct URL, http://www.htiripm.colostate.edu. Future site maintenance will be handled by the Department of Soil and Crops Sciences at Colorado State University.

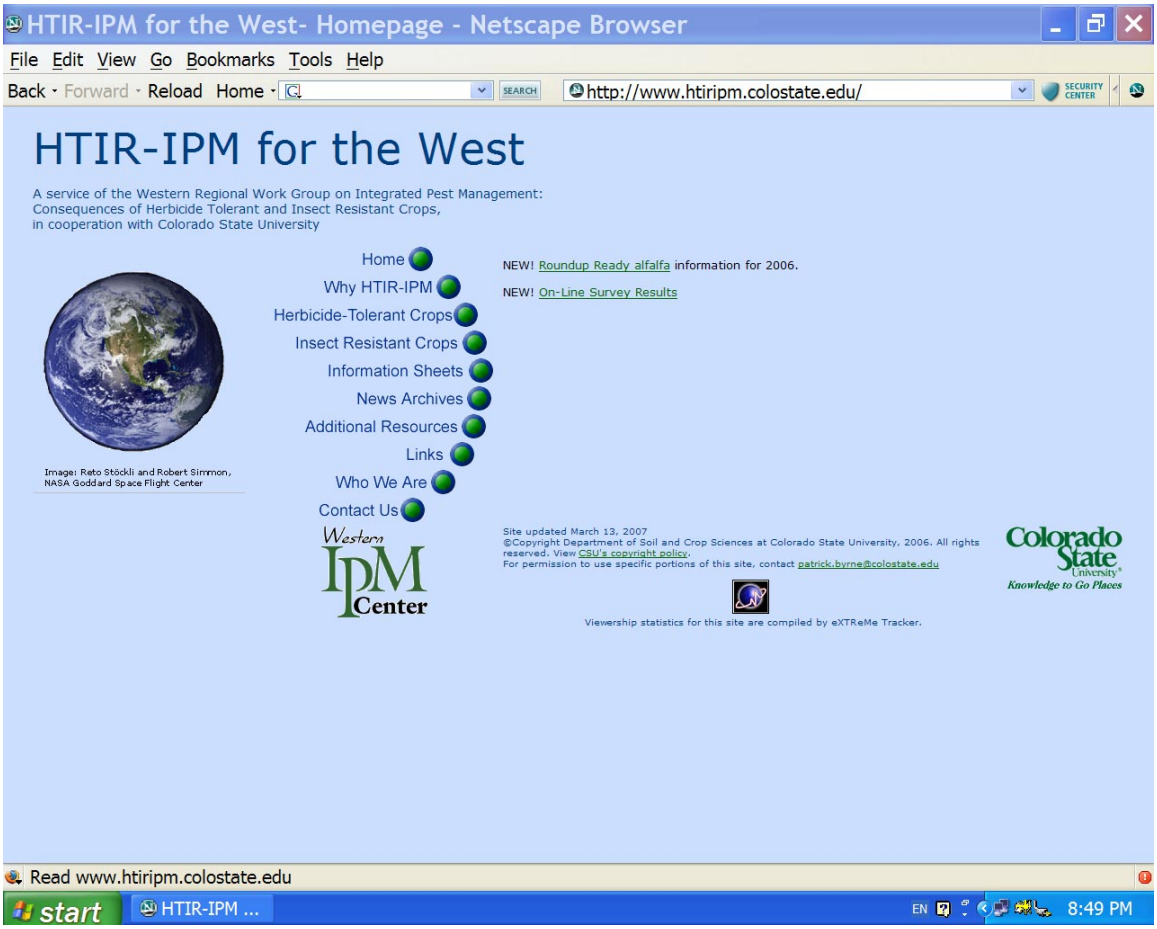

Fig. 1. Home page of the work group web site.

IV. On-line survey

We developed a survey and conducted it online from April 11 to October 12, 2005. The survey gathered information about the participant's home state, occupation, and employer, experience with HTIR cultivars, and perceptions of the important issues and the potential risks and benefits associated with these cultivars in the Western U.S. Participants rated the usefulness of existing and potential cultivars in Western farming systems, 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 farming systems. Participants also indicated whether sufficient information was available on IPM practices in HT and IR crops, and rated their preferences for receiving this information. 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.

Highlights of survey results

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 Western states were represented.

Changes in farming practices for HT crops

All weed control practices were perceived to have declined. Reductions in tillage and in the use of multiple herbicides are expected results of the use of HT crops. However there were also perceived reductions in herbicide rotation, crop rotation, and the use of a combination of methods, suggesting a potential for the development of herbicide resistance in weeds due to a decline in IPM practices.

Changes in farming practices for IR crops

Changes in insect pest management practices generally did not indicate a move away from IPM approaches. The majority of participants perceived similar or increased use of biological control, scouting, crop rotation, and other cultural controls. Declines were seen in the use of both broad-spectrum and selective insecticides.

Usefulness of HT crops

Four Roundup Ready crops -- sugar beet, cotton, canola, and corn – were rated as highly useful (>4 on a 5-point scale) and moderately likely to cause problems. Clearfield sunflower, Clearfield wheat, and Roundup Ready alfalfa were rated moderate in both usefulness and potential for problems. Roundup Ready spring wheat and winter wheat received higher ratings for problem-causing potential than for usefulness.

Usefulness of IR crops

All IR crops received a usefulness rating of 3 or more (on a 5-point scale) and all received usefulness ratings higher than the corresponding rating for potential to cause problems.

Potential problems perceived in HT crops

The most serious were considered to be

- shifts in weed species composition and
- development of herbicide tolerance in weeds due to repeated applications of a herbicide.

Potential problems perceived in IR crops

The greatest concerns about the potential consequences of IR crops were

- development of resistance in target pests and
- difficulties associated with management of refugia.

A detailed breakdown of the survey responses is posted on the HTIR web site (http://www.htiripm.colostate.edu). Graphs show the percentage of respondents who chose each possible response to the survey questions. A manuscript describing the survey results has been submitted to the peer-reviewed online journal AgBioForum (www.agbioforum.missouri.edu/)

V. Video conferencing

Our work group held small video conferences throughout the two-year project. Group members informally judged the video conferences to be helpful for small group meetings. The value of being able to put a face and a voice to a name was rated high by some participants, but the limit of four faces on screen at one time reduced the utility of the video conferences when the group was large. The most talkative members tended to dominate the screen, because the conferencing software was voice-activated, putting on screen the faces of the people who were speaking or had spoken recently. Small meetings allowed a relatively non-talkative participant's face to remain on screen rather than being supplanted by more talkative group members.

All group members were able to install the video conferencing software and operate the equipment with very little difficulty. The university's conferencing system worked reliably, although older wiring in one building on the CSU campus limited the connection to one video camera for three people housed in that building. We were not able to resolve the inability of one group member to participate in video conferences using an Apple computer. An Apple system was tested successfully on campus and from a remote location in Fort Collins, but unidentified problems prevented a successful connection from Arizona to CSU.

VI. Budget

Budget item	**Amount budgeted**	**Amount spent**
Salary and fringe benefits for a research associate and student hourly	$8,023	$12,417
Video conferencing supplies	6,950	4,341
Professional meeting expenses (travel, registration, poster printing, and related expenses)	2,800	1,016
Indirect costs (19% of total)	4,169	4,168
Total	$21,942	$21,942

VII. Priorities for research, information, and education needs

Listed below are the research, information, and education priorities that arose from discussions among the workgroup members and/or that were indicated as important issues by respondents to our online survey.

A. Research priorities

Herbicide Tolerance

1. **Is there evidence of weed shifts or herbicide resistance in weeds in the Western U.S.?** This becomes an especially relevant question given the increasing number of crop varieties with resistance to a single herbicide (e.g., Roundup Ready and Clearfield crops). To date, Roundup Ready cotton has changed the density of some weed species (e.g., purple and yellow nutsedge) in other regions, but there has not been much change in the weed species complex found in Arizona. However, in other systems (e.g., tree crops/orchards), there has been a dramatic, multispecies shift in weed composition when multiple glyphosate applications are made per year. The introduction and adoption of new herbicide-tolerant crops (e.g., Roundup Ready alfalfa, Roundup Ready Flex cotton) together with existing herbicide-tolerant crops raises serious questions about the effects on weed populations.

2. **What are the mechanisms of herbicide resistance in weed species** (e.g., modifications of the herbicide's site of action; herbicide metabolism; herbicide translocation) and what is the nature of inheritance (e.g., dominant vs. additive; quantitative vs. single gene; cytoplasmic vs. nuclear)? Powles and Preston (2006) document two mechanisms of resistance to glyphosate, but other mechanisms are also likely to become apparent. Although the immediate concern is to better understand weed resistance to glyphosate, it will also be important to study herbicide resistance associated with non-glyphosate herbicides used to manage glyphosate-resistant weeds in glyphosate-tolerant crops.

3. **What is the frequency and potential impact of introgression of HT or IR genes from crops to wild species?** For crop-to-wild gene flow, the frequencies of initial hybridization events have been estimated for most of the relevant Western crops (e.g., wheat to jointed goatgrass; canola to wild *Brassica* species; domesticated sunflower to wild sunflower). However, the next steps (successive backcrosses and stable introgression into wild populations) are not completely understood. Therefore, research on the occurrence and frequency of these events is a priority for risk assessment. Another important objective of gene flow research will be to investigate the ecological impacts of gene introgressions if they do occur.

4. **What are the optimum IPM strategies for sustainable weed control with HT crops**, i.e., which combinations of herbicides, herbicide rates, crop rotations, and cultural practices are most cost effective and environmentally responsible?

Insect Resistance

1. **Are levels of Bt resistance increasing in corn borers or corn rootworm as a result of Bt corn?** Monitoring for resistance in Bt target pests is difficult because resistance alleles are rare and difficult to detect in the heterozygous state. However, two recent examples of Bt resistance monitoring were recently published: Tabashnik et al. (2006) on monitoring for resistance alleles in pink bollworm in Arizona cotton, and Huang et al. (2007) on monitoring for resistance alleles in southwestern corn borer in Louisiana corn. Similar studies would be useful for European corn borer and Western corn rootworm in the Western U.S.

2. **What is the biotype composition of Russian wheat aphid (RWA) and how does it affect pest management?** New, damaging biotypes of RWA were discovered in southeastern Colorado and adjoining states in 2003 and 2004. These biotypes overcame the current levels of resistance incorporated in existing wheat cultivars. The crucial questions now are: What RWA biotypes are present in wheat, barley, and other host grasses? How does biotype composition in wheat and barley change over time? When and where are males present? Do biotypes vary in pest management requirements, other than cultivar selection?

Both Herbicide Tolerance and Insect Resistance

1. **What are the best IPM practices for pest control in reduced tillage systems?** No-till or minimum-till systems merit special consideration because pest problems may be different than with conventional tillage, and the use of an important weed control method (tillage) is minimized. Therefore, another research priority is to develop an integrated, comprehensive system for managing pests (weeds, insects, diseases) in no-till cropping systems. Research by Blackshaw et al. (2005, Weed Sci. 53:528-535) is an example of the kind of work that is needed.

B. Information priorities

Both Herbicide Tolerance and Insect Resistance

1. **What is the acreage of HT and IR crops in the Western region?** In the process of investigating HT and IR crop use in the West, we found that it was not easy to locate data on the regional acreage of these crops or how the acreage was distributed among the states. USDA's National Agricultural Statistics Service (NASS, http://www.nass.usda.gov/) does a partial job, by reporting the acreage of genetically engineered (GE) HT and IR cultivars for a subset of crops and states. For example, NASS reports total cotton acreage for California, Arizona, and New Mexico, but the percent of acreage planted to HT and IR cultivars is given only for California. Total acreage of corn is reported for 11 Western states, but HT and IR percentages are not reported for any of those states. For non-GE cultivars, no information is provided by NASS. Therefore, an important information need is for regular estimates of the percent of total crop acreage planted to HT and IR cultivars, by state in the Western region. Perhaps every two years would be often enough to track usage trends. Even more useful would be information broken down by specific trait, e.g., not simply Bt corn, but Bt for corn

borer control and Bt for corn rootworm control. Similarly, information on specific IR genes in cotton would be helpful. This data collection could potentially be undertaken by NASS, as they apparently already conduct surveys on total crop acreage in the West. It might also be undertaken by the Western IPM Center or a national group such as the National Center for Food and Agricultural Policy (http://www.ncfap.org/), which issues periodic reports on the use of GE cultivars.

2. **How are HT and IR cultivars being used in cropping systems?** Are HT cultivars planted for general weed control or to control specific weeds on an occasional basis? Are IR cultivars planted based on the predicted presence of pests, as an "insurance policy" in case there is a pest outbreak, or because the IR trait comes as part of a "stacked" trait package?

3. **To what extent are refuge requirements, stewardship recommendations, and appropriate IPM practices (e.g., rotating herbicides and crops) being followed?** If growers are not following the guidelines, why not? Is it for lack of information, confusion about refuge requirements (e.g., for combined Bt corn borer + Bt corn rootworm hybrids), economic or time constraints, or some other reason?

C. Education priorities

Improved educational materials or programs will be valuable for a number of topics. Based on our online survey results (Harrington et al., submitted), the preferred means of information delivery are fact sheets, workshops, and university web sites. Priorities for educational programs are those that

1. Explain the effects of selection pressure on both resistance development and species shifts.

2. Explain how reduced herbicide application rates might impact resistance development.

3. Explain the mechanisms of gene flow, its potential consequences, and ways to minimize it.

4. Provide cross-commodity information on herbicides to avoid grower confusion about which crops can be planted when.

5. Describe the equivalencies among all types, brands, and concentrations of glyphosate.

VIII. References

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