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Herbicide-Resistant Weeds in the United States and Their Impact on Extension

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Herbicide-resistant weeds have impacted crop production throughout the United States, but the effect they have on extension programming has not been evaluated. In June 2007, 38 extension weed specialists throughout the United States, responded to a survey on herbicide-resistant (HR) weeds and the impact they are having on extension education programming. Survey results revealed that HR weeds have had a significant impact on extension programming particularly for agronomic crops. In the last 10 yr, agronomic weed specialists' extension programming was almost twice as likely to be impacted by the presence of HR weeds as compared to horticultural programming. In the next 5 yr, agronomic extension programming is twice as likely to be altered. Of 37 weed species reported, seven genera or species of weeds represented 80% of the major HR biotypes reported. These include *Amaranthus* species, horseweed, *Setaria* species, common lambsquarters, kochia, giant ragweed, and *Lolium* species. Five weed species (common ragweed, common lambsquarters, horseweed, kochia, and three foxtail species) exhibited weed by mode of action (MOA) interactions when evaluated as major or minor problems. Herbicide resistance problem severity differed for weed species, herbicide MOA, and crops. The results of this survey of university extension personnel confirm that HR weeds have impacted extension programming and will continue to impact programming in the future.

Nomenclature: Common lambsquarters, *Chenopodium album* L. CHEAL; common ragweed, *Ambrosia artemisiifolia* L. AMBEL; giant foxtail, *Setaria faberi* Herrm. SETFA; giant ragweed, *Ambrosia trifida* L.; green foxtail, *Setaria viridis* (L.) Beauv. SETVI; horseweed, *Conyza canadensis* (L.) Cronq. ERICA; kochia, *Kochia scoparia* (L.) Schrad. KCHSC; yellow foxtail, *Setaria pumila* (Poir.) Roemer & J.A. Schultes SETLU.

Key words: Acetyl CoA carboxylase (ACCase) inhibitors, acetolactate synthase (ALS) inhibitors, triazines, EPSP synthase inhibitors, survey, extension.

Chemical weed control is the mainstay of weed management in current American agriculture. The loss or reduction in the utility of herbicides is a concern to researchers, agronomists, agribusiness, and farmers. Resistance is one mechanism of reducing the utility of a herbicide, and over the past three decades, reports of herbicide-resistant (HR) weed biotypes have increased (Heap 2008). Thus, herbicide resistance has been an important topic for weed management, and resistance has become a focal point of many extension programs.

Surveys are one method of gathering information from a large pool of individuals to develop an understanding of behavior and attitudes. These have been used by weed scientists to understand farmers' and crop consultants' perceptions on weed (Johnson and Gibson 2006; Norsworthy et al. 2007; Wilson et al. 2008). Surveys have also been used with extension specialists to obtain an expert opinion of what is occurring in their region (Shaner 1995). Surveys of extension specialists have been used to understand growers' attitudes as well as to develop databases on weed species (Culpepper 2006; Webster and Coble 1997). Formal surveys have the advantage over informal discussion among colleagues because everyone is responding to the same set of questions.

Although many surveys and lists of herbicide-resistant weeds exist, the HR biotypes are not differentiated based on level of concern. We developed a survey in order to gain a better understanding of how extension programming was responding to herbicide-resistant weeds. The survey was designed to determine if and how herbicide-resistant weeds have impacted extension educational programs, and which HR weeds are the most troublesome. Furthermore, we wanted to determine if differences existed for specialists by region (midwest, west, northeast, or south) and by responsibility (agronomic or horticultural).

Materials and Methods

In June 2007, university extension specialists were asked to participate in an on-line survey consisting of open-ended questions as well as multiple-response questions. Participants were university agronomic and horticultural weed extension specialists throughout the United States that work with feed or food commodities. These specialists were chosen to represent all regions of the United States and included a range of food and agronomic crops. Thirty-eight responses were received out of 43 requests.

The survey was divided into three sections. The first section was to identify major and minor HR weeds by crop, followed by why these weeds were considered a problem. Criteria to distinguish major from minor problems were not provided, so respondents made their own determination. The second section was designed to determine changes in extension programming over the last 10 yr and what resistance topics are emphasized. A final set of questions was directed at determining what percentage of growers utilizes resistance management practices to avoid development of HR weeds and reasons for not implementing resistance management. Most questions in the second and third sections were designed to either allow respondents to choose from a list of answers that

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Table 1. Herbicide-resistance impact on extension programming: topics most commonly addressed.

Topic commonly addressed	Weight of specialist response[a]
	%
Discuss control of specific herbicide-resistant biotypes	90
Emphasize resistance avoidance	87
Emphasize integration of nonherbicidal weed control	69
Discuss mechanisms of resistance	58
Discuss herbicide mode of action numbering system	43
Other	16

[a] Specialists were asked to choose whether topics were commonly discussed, not commonly discussed, or not discussed. For the purpose of data analysis, commonly discussed answers were assigned a value of 3, not commonly discussed assigned a value of 1, and not discussed a value of 0. Percentage reflects the weight of the topic based on respondent answers.

Table 2. Most common reasons growers cite for not implementing preventative resistance management strategies.

Reasons most commonly cited	Weight of specialist response[a]
	%
Will wait until herbicide-resistant biotypes are on-farm	71
Preventative management is too costly	68
Believe new mode of actions will become available to manage herbicide-resistant biotypes	62
High percentage of rental land and may not reap the investment	53
No effective alternatives available	50
Strategies are too management intensive	49
Herbicide mode of action too confusing to understand	28
Other	12

[a] Specialists were asked to choose if topics were commonly discussed, not commonly discussed, or not discussed. For the purpose of data analysis, commonly discussed answers were assigned a value of 3, not commonly discussed assigned a value of 1, and not discussed a value of 0. Percentage reflects the weight of the topic based on respondent answers.

allowed a range of responses to be selected or to answer either yes or no. In two instances (results reported in Tables 1 and 2) specialists were asked if issues were commonly discussed, not commonly discussed, or not discussed. In order to determine separation between these issues, responses were weighted such that commonly discussed issues were assigned a value of 3, not commonly discussed assigned a value of 1, and not discussed assigned a value of 0.

Data were entered into a spreadsheet and coded numerically for analysis. The summation of the data was performed and results, unless otherwise stated, are presented as the percent of those responding to the question. Differences were determined with the use of nonparametric analysis (NPAR1-WAY Savage one-way chi-square test for equality of distributions or NPAR1WAY analysis of variance, SAS) and are significant at 0.05 levels unless otherwise stated.

Results and Discussion

Summary of Raw Data. Thirty-eight extension specialists (28 agronomists and 10 horticulturalists) identified 339 occurrences of major and minor HR weed concerns. Twenty-eight states were represented in this survey; only one reported no HR biotypes (Arizona). Included in the survey were 37 weed species consisting of 26 species classified strictly as summer annuals, 12 herbicide modes of action (MOA), and 27 crops. Respondents cited 194 major HR biotypes/crop issues and 145 minor issues. By far, responses of HR *Amaranthus* species outnumbered any other genus with 28% of the total reported. Two *Ambrosia* species accounted for nearly 15% of the total reported troublesome weeds, followed by horseweed, accounting for nearly 10%. Six weed species were reported with multiple HR biotypes and consisted of common ragweed, giant ragweed, horseweed, waterhemp (*Amaranthus rudis* Sauer), smooth pigweed (*Amaranthus hybridus* L.), and kochia. It should be noted that the survey did not ask about multiple resistance, but these species were mentioned by the respondents. Three species were unique to horticulture, including dandelion (*Taraxacum officinale* Weber in Wiggers), livid amaranth (*Amaranthus lividus* auct. Non L.), and common purslane (*Portulaca pilosa* L.). Nine species were listed only as minor problems, including bushy wallflower (*Erysimum repandum* L.), common cocklebur (*Xanthium strumarium* L.), common groundsel (*Senecio vulgaris* L.), common purslane, goosegrass [*Eleusine indica* (L.) Gaertn.], johnsongrass [*Sorghum halepense* (L.) Pers.], marshelder (*Iva xanthifolia* Nutt.), volunteer corn (*Zea mays* L.), and Virginia pepperweed (*Lepidium virginicum* L.).

Twelve herbicide MOA were reported and four of those, acetyl CoA carboxylase (ACCase) inhibitors, acetolactate synthase (ALS) inhibitors, triazines, and EPSP synthase inhibitors (groups 1, 2, 5, and 9, respectively), represented 89% of all reported HR weed problems. Crops included corn, soybean [*Glycine max* (L.) Merr.], cotton (*Gossypium hirsutum* L.), small grains, other agronomic crops, fruits and vegetables, and various others such as roadsides and Christmas trees. Due to the majority of the survey population being agronomists and the acres treated with herbicides being corn and soybeans, it is not surprising that 56% of HR occurrences reported were listed in these two crops.

Survey results showed that HR weeds have impacted educational programming. Over 80% of extension specialists reported spending more effort on herbicide resistance in 2007 than they spent 10 yr earlier, and almost 70% reported they expect herbicide resistance to continue to impact their extension programming in the next 5 yr. The two main HR topics extension specialists address are management of a specific HR biotype and resistance management strategies to avoid the development of HR biotypes (Table 1). Thirty-seven percent of the extension specialists said they emphasize a particular MOA over others, with EPSP synthase-inhibiting and acetolactate synthase (ALS) inhibiting MOA being the MOAs of greatest concern. The 2–1–2 approach (using only two applications of a herbicide MOA on any one field over a 2-yr period) was discussed by only 16% of the extension specialists in this survey.

Table 3. Herbicide-resistant (HR) biotypes reported by weed extension specialists. Specialists were asked to specify which biotypes were major issues and which were minor issues in their area.

HR weed	Total instances reported	No. cited as major issue	No. cited as minor issue
Amaranthus spp.	96	55	41
Horseweed	34	32	2
Common ragweed	32	8	24
Setaria spp.	28	18	10
Common lambsquarters	26	14	12
Kochia	21	14	7
Giant ragweed	18	12	6
Lolium spp.	14	11	3
Sorghum spp.	8	2	6
Avena spp.	7	4	3
Solanum spp.	6	2	4
Velvetleaf (*Abutilon theophrasti* Medik.)	6	4	2
Goosegrass	5	0	5
Russian thistle	5	5	0
Common groundsel	4	0	4
Corn (volunteer)	4	0	4
Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]	3	2	1
Common cocklebur	3	0	3
Prickly lettuce (*Lactuca serriola* L.)	3	2	1
Marshelder	3	0	3
Other[a]	13	9	4

[a] Other species were cited less than three times.

Table 4. Herbicide MOA comparison reported as major problems. Percentages represent the frequency of major issues with each herbicide MOA versus the total reported issues with that MOA.

MOA	Percent of total cited as major issue	Total instances reported
ALS[a]	63	141
EPSP synthase	65	80
ACCase	70	27
PGRs	71	7
Ureas	100	1

[a] Abbreviations: MOA, mode of action; ALS, acetolactate synthase (Group 2); EPSP, 5-enolpyruvl-shikimate-3-phosphate (Group 9); ACCase, acetyl CoA carboxylase (Group 1); PGRs, plant growth regulators (Group 4); ureas (Group 7).

Extension personnel were asked to estimate the percentage of growers in their area using resistance management practices to avoid the development of HR biotypes. The majority (61%) estimated that between 25 and 75% of growers in their area utilized preventative practices. Respondents also reported on what reasons growers commonly gave for not implementing a preventative HR weed strategy. Seventy-one percent of respondents reported that these growers had the attitude they would wait and deal with HR weeds if/when they occurred (Table 2). Other common responses for nonacceptance were preventative HR management was too costly (68%) and a belief that new herbicide MOA will become available in the future (62%).

Major versus Minor Problems: Crops, Weeds, and MOA. Crops were divided into seven categories. Corn, soybean, small grains, and cotton were four of the crops reported with HR biotypes. A fruit and vegetable category consisted of asparagus (*Asparagus officinalis* L.), blueberry (*Vaccinium corymbosum* L.), carrot (*Daucus carota* L.), sweet corn (*Zea mays* L. Convar. Saccharata Koern.), lettuce (*Lactuca sativa* L.), pepper (*Capsicum annuum* L.), strawberry (*Fragaria ananassa* L.), tomato (*Solanum lycopersicum* L.), vineyards, and watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai]. Other agronomic crops included alfalfa (*Medicago sativa* L.), dry beans (*Phaseolus vulgaris* L.), cowpea [*Vigna unguiculata* (L.) Walp.], grain legumes, sorghum [*Sorghum bicolor* (L.) Moench], peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), rice (*Oryza sativa* L.), sugar beet (*Beta vulgaris* L.), and sunflower (*Helianthus anuus* L.). A seventh category, referred to as "other," contained HR reports in nurseries, roadsides, orchards, and in nut trees. Comparison of these seven categories resulted in no significant differences; as a main effect, no single category mentioned above was reported to have greater or lesser frequency of major or minor problems than any other category.

Several HR weed species were frequently reported as major problems. Seven genera or species of weeds represented 80% of the major HR biotypes reported (Table 3). These include *Amaranthus* species, horseweed, *Setaria* species, common lambsquarters, kochia, giant ragweed, and *Lolium* species. Nine out of 20 genera or species reported were listed as a major problem at least 60% of the time.

Herbicide MOA comparison showed five MOA were reported as major problems, with three of those representing the majority of the total reported (Table 4). ALS-, EPSP synthase-, and ACCase-inhibiting resistant biotypes were cited as major problems 63, 65, and 70% of the time, respectively.

Weed species by MOA interactions were noted with five species. ALS-resistant common ragweed was more often reported as a major problem as compared to *Ambrosia* species resistant to other MOA (Table 5). However, PPO-, triazine-, and EPSP-resistant *Ambrosia* species were more often reported as minor problems than as major problems. Triazine- and ALS-resistant *Chenopodium* species were more often reported as a major problem as compared to EPSP-resistant *Chenopodium* species. ALS-resistant and EPSP-resistant horseweed were more often reported as a major problem, whereas triazine-resistant horseweed was reported a minor HR problem. ALS-resistant kochia was more often reported as a major problem, whereas triazine-resistant kochia was only reported as a minor HR problem. ACCase-, triazine-, and ALS-resistant *Setaria* species (3) were more often reported as major problems, whereas *Setaria* biotypes resistant to the dinitroaniline (DNAs) were reported only as a minor HR weed problem.

Weed by crop interactions were noted with only soybean and cotton. *Amaranthus* species (4), giant ragweed, and horseweed were frequently cited as a major HR weed problem in soybean and cotton (Table 6).

Two crop by MOA interactions were observed. In the other agronomic crops category, resistance to ACCase, photosystem II inhibitor (ureas), and plant growth regulators were noted as major problems. In fruit and vegetable crops, ALS and EPSP inhibitors were frequently cited as major problems (significant at the 0.1 level)(Table 7). Extension specialists reported

Table 5. Weed-by-MOA interaction. Five HR weed species, AMBEL, CHEAL, ERICA, KCHSC, and *Setaria* spp. (3), are ranked as a major (positive 1) or minor (negative 1) HR weed problem. A dash denotes no report of resistance to that herbicide MOA as reported in this survey.

	Herbicide-resistant weed ranking				
MOA	AMBEL	CHEAL	ERICA	KCHSC	*Setaria* spp.
ALS[a]	0.31	0.60	0.06	0.16	0.07
Triazines	−0.45	0.24	−0.95	−0.79	0.43
EPSP	−0.45	−0.70	0.03	—	—
ACCase	—	—	—	—	0.23
PGRs	—	—	—	0.00	—
PPOs	−0.45	—	—	—	—
DNAs	—	—	—	—	−0.78

[a] Abbreviations: MOA, mode of action; HR, herbicide resistant; AMBEL, common ragweed; CHEAL, common lambsquarters; ERICA, horseweed; KCHSC, kochia; ALS, acetolactate synthase (Group 2); triazines (Group 5); EPSP, 5-enolpyruvl-shikimate-3-phosphate (Group 9); ACCase, acetyl CoA carboxylase (Group 1); PGRs, plant growth regulators (Group 4); PPO, protoporphyrinogen oxidase inhibitors (Group 14); DNAs, dinitroanilines (Group 3).

EPSP-resistant weeds were problematic in fruit and vegetable crops due to poor control in the previous year's row crop.

Differences by Responsibility: Agronomic versus Horticultural. When asked to compare their present extension program versus that of 10 yr ago, 96% of agronomic weed specialists reported their programs have been altered because of HR weeds, whereas 56% of horticultural weed specialists reported an effect on their program. Approximately 80% of agronomic specialists anticipated altering their extension programs because of HR weeds over the next 5 yr as compared to 44% of horticultural specialists.

Both agronomic and horticultural weed specialists reported placing the same amount of emphasis on mechanisms of resistance, herbicide mode of action numbering systems, and the integration of nonherbicidal weed control in their extension programs. Agronomic specialists were more likely to discuss control of specific HR biotypes and resistance avoidance, as compared to horticultural specialists.

Few agronomic and horticultural weed specialists, 18 and 11% respectively, reported discussing the 2–1–2 approach (using only two applications of a herbicide MOA on any one field/site over a 2-yr period). The majority of both groups of extension specialists reported placing similar emphasis on herbicide resistance, regardless of MOA.

As previously mentioned, the majority of both groups of specialists estimated that 25 to 75% of growers were currently using resistance management practices to avoid the development of HR weeds. Specialists were asked to comment on likely reasons why growers did not implement preventative resistance management practices. Compared to horticultural weed specialists, agronomic weed specialists reported growers were more likely not to implement preventative resistance management because: (1) preventative efforts were too management intensive; (2) high percentage of rental land; and (3) resistance management was too costly. Agronomic weed specialists also reported a larger number of growers they work with held the attitude of "why deal with resistance now, they will wait until it shows up." Both groups of specialists reported similar grower attitudes toward not implementing preventative resistance management: (1) lack of effective

Table 6. Weed by crop interaction. Herbicide-resistant (HR) weeds in soybean and cotton ranked as a major (positive 1) or minor (negative 1) problem. Miscellaneous includes Russian thistle [*Salsola iberica* (Sennen & Pau) Botsch. ex Czerep.], wild carrot (*Daucus carota* L.), cocklebur (*Xanthium strumarium* L.), marshelder, and volunteer corn. The actual number of times a weed was cited appears next to its ranking. A dash denotes no report of resistant weed species in that crop reported in this survey.

	Soybean		Cotton	
HR weed	Ranking	No. cited	Ranking	No. cited
Sorghum spp.[a]	−0.77	2	−0.69	1
Goosegrass	−0.77	1	−0.69	3
Eastern black nightshade (*Solanum ptycanthum* Dunal)	−0.36	3	—	—
Common ragweed	−0.32	14	−0.69	1
Common lambsquarters	−0.15	6	−0.69	2
Kochia	−0.15	4	—	—
Setaria spp. (3)	−0.08	9	—	—
Miscellaneous	−0.02	5	−0.69	2
Amaranthus spp.[b]	0.03	34	0.31	12
Giant ragweed	0.14	11	0.64	1
Velvetleaf	0.48	1	—	—
Horseweed	0.48	15	0.64	4

[a] Two HR *Sorghum* species were cited in soybean and one in cotton.

[b] Four HR *Amaranthus* species were cited in soybean and two were cited in cotton.

Table 7. Crop by mode of action (MOA) interaction. MOA used in fruit and vegetable crops and the MOA used in other agronomic crops ranked as a major (positive 1) or minor (negative 1) problem. Fruit and vegetable crops include asparagus, blueberry, carrot, sweet corn, lettuce, pepper, strawberry, tomato, vineyards, and watermelon. Other agronomic crops include alfalfa, dry beans, cowpea, grain legumes, sorghum, peanut, potato, rice, and sugar beet. A dash denotes no report of resistance to that herbicide MOA as reported in this survey.

MOA	Fruit/vegetable*	Other agronomic crops**
ACCase	—	0.56
PGRs	—	0.56
Ureas	—	0.56
ALS inhibitors	0.63	−0.09
Triazines	−0.25	−0.09
Dinitroanilines	—	−0.73
EPSP inhibitors	0.63	−0.73
Bipyridyliums	−0.03	—
Other	−0.69	—

* Significant at $P = 0.10$.

** Significant at $P = 0.05$.

Table 8. Comparison of extension specialists' response to why a specific herbicide-resistant (HR) weed biotype was considered a major or minor problem.[a]

Extension responsibility	HR weed biotypes considered a major problem: Lack of effective control	Cost of alternative control	Widespread distribution	HR weed biotypes considered a minor problem: Effective alternative controls	Only localized infestations
	%				
Agronomic	47	43	64	63	84
Horticultural	53*	29*	35**	60*	40**

[a] Differences are based on nonparametric analysis of variance. Comparisons are made within columns only.

* Significant at P = 0.10.

** Significant at P = 0.05.

alternative controls, (2) herbicide MOA were too confusing, and (3) the belief that new MOA would soon be on the market to alleviate the problem.

The most frequently reported agronomic consideration for determining an HR biotype as a major problem was due to the HR weeds' "widespread distribution" (64%), whereas the majority of horticultural specialists (53%) considered "lack of effective control" to be the determining factor (Table 8). Similarly, "only localized infestations" was most often cited by agronomic specialists (84%) as the determining factor as a minor problem, compared to horticultural specialists' most common response, "effective alternative controls."

Differences by Region (Midwest, Northeast, South, West). Two differences in agronomic weed specialist responses were noted between regions. When asked why growers would choose not to implement resistance management practices in order to avoid HR weeds, extension specialists from the West reported growers felt a greater benefit to waiting until the problem presented itself. Specialists from the West also reported that growers in their area were less likely to believe new MOA would soon become available to solve their HR problems as compared to the responses of extension specialists from the Midwest, Northeast, and the South.

Although horticultural and agronomic specialists may tend to differ on the criteria for determining what constitutes a major/minor HR weed problem, and what aspects of prevention and control to emphasize, the majority of these specialists' current extension programs have been altered to address grower awareness of HR weeds in their commodity. With the continual rise in HR weed occurrences, and dwindling numbers of alternative herbicides, extension plays an integral role in educating growers on HR topics. It is likely that even greater emphasis will be placed on HR avoidance and alternative control options in the future.

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