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Benchmark Study: I. Introduction, Weed Population, and Management Trends from the Benchmark Survey 2010

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Almost 1,650 corn, cotton, and soybean growers in 22 states participated in a 2010 telephone survey to determine their attitudes with regard to which weed species were most problematic in glyphosate-resistant (GR) crop production systems for corn, cotton, and soybean. The survey is a follow-up to a previous 2005 to 2006 survey that utilized a smaller set of growers from fewer states. In general, growers continued to estimate weed populations as low and few challenges have been created following adoption of GR cropping systems. Pigweed and foxtail species were dominant overall, whereas other species were more commodity and state specific. Corn, cotton, and soybean growers cited velvetleaf, annual morningglory, and waterhemp, respectively, as predominant weeds. Growers in the South region were more likely to report pigweed and waterhemp (*Amaranthus* spp.), whereas growers in the East and West reported horseweed. When growers were asked with which GR weeds they had experienced personally, horseweed was reported in all regions, but growers in the South more frequently reported pigweed, whereas growers in the East and West regions more frequently reported waterhemp. Comparisons with the previous 2005 survey indicated that more growers believed they were experiencing GR weeds and were more aware of specific examples in their state. In particular, the *Amaranthus* complex was of greatest concern in continuously cropped soybean and cotton.
Nomenclature: Glyphosate; horseweed, *Conyza canadensis* (L.) Cronq.; velvetleaf, *Abutilon theophrasti* Medic.; waterhemp, *Amaranthus tuberculatus* (Moq.) Sauer; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; soybean, *Glycine max* (L.) Merr.
Key words: Glyphosate-resistant crops, resistance management, grower survey.

En 2010, casi 1,650 productores de maíz, algodón y soya en 22 estados participaron en una encuesta telefónica para determinar sus actitudes en referencia a qué tipo de malezas fueron las más problemáticas en los sistemas de producción de cultivos resistentes a glyphosate para maíz, algodón y soya resistentes a este herbicida. Esta encuesta es el seguimiento de otra realizada en 2005–2006, la cual utilizó un grupo menor de productores en y se realizó en menos estados. En general, los productores siguieron estimando las poblaciones de malezas como bajas y pocos retos han sido creados después de la adopción de sistemas de cultivos resistentes a glyphosate. En general, las especies de los géneros *Amaranthus* y *Setaria* fueron las dominantes, mientras otras especies fueron más específicas de acuerdo al cultivo o al estado. Los productores de maíz, algodón y soya mencionaron *Abutilon theophrasti*, especies anuales del género *Ipomoea* y *Amaranthus tuberculatus*, respectivamente, como malezas predominantes. Los productores en la región sur reportaron *Amarantus* spp. con mayor frecuencia, en tanto que los agricultores de las regiones este y oeste reportaron *Conyza canadensis*. Cuando se les preguntó a los agricultores con cuáles malezas resistentes a glyphosate habían tenido experiencia personalmente, *Conyza canadensis* se reportó en todas las regiones, pero los agricultores en el sur reportaron *Amaranthus* más frecuentemente, mientras los productores de las regiones este y oeste reportaron más frecuentemente *A. tuberculatus*. Las comparaciones con la encuesta previa de 2005 indicaron que más agricultores creyeron haber experimentado una mayor incidencia de malezas resistentes a glyphosate y sabían de más ejemplos específicos en su estado. Particularmente, el complejo *Amaranthus* fue una de las mayores preocupaciones en soya y algodón en cultivo continuo.

Much attention has been given to the increase in glyphosate resistance within the agriculture community. To date, 21 species of weeds have been identified as having evolved glyphosate resistance, making resistance a major obstacle for today's growers in many crop systems (Heap 2011). However, problems arising from GR weed biotypes have not lessened the importance of GR crops. In 2009, producers continued to favor genetically modified cultivars of soybean, corn, and cotton in large percentages, a trend since these technologies became available in the late 1990s. To date 64 million ha have been planted with crops genetically modified with enhanced pest management traits, of which the majority are GR (James 2009).

Empirically, glyphosate resistance evolves from monoculture cropping systems without diversity in herbicide selection (Gressel and Segel 1990). Several surveys have been conducted in recent years that focused on grower attitudes and perceptions about the evolution and management of glyphosate resistance in weeds. Previous survey results showed in most instances that for GR cotton, GR soybean, and GR corn, glyphosate has become the core, if not sole, herbicide used by growers for weed management (Givens et al. 2009a). Glyphosate use increased at the expense of a decrease in utilization of other herbicides and

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mechanisms of action. Increased reliance on herbicides for weed management often occurs following the adoption of reduced-tillage systems, and survey results showed clearly that producers in a crop rotation that included a GR crop adopted reduced-tillage systems more frequently than in the past. Growers in a crop rotation that included a GR crop shifted to a less intensive tillage system (either reduced or no tillage) or remained in a less intensive tillage system after adopting a GR crop in the majority of cases (Givens et al. 2009b). Culpepper (2006) reported that weed population shifts occurred in response to reduced tillage and decreased use of residual herbicides. As such, there is no question that the advent of GR cropping systems has contributed to weed species shifts as continuous, repetitive use of glyphosate selected for weeds most tolerant to glyphosate, particularly when other control methods were not utilized.

Weed population shifts and substantial changes in management predicated on GR cropping systems have increased the need to define prevalence and distribution of GR weeds that are problems in GR corn, cotton, and soybean. Webster and MacDonald (2001) reported that Texas panicum (*Panicum texanum* Buckl.) and sicklepod (*Senna obtusifolia* (L.) Irwin and Barnaby) were the most troublesome weeds in corn, whereas morningglory (*Ipomoea* spp.) and pigweed (*Amaranthus* spp.) were also listed in Georgia. Sicklepod was the most troublesome weed, followed by pigweed and morningglory species in cotton. With the exception of Palmer amaranth (*Amaranthus palmeri* S. Wats.), none of these weeds is currently listed as resistant to glyphosate (Heap 2011). Kruger et al. (2009) surveyed growers about the most problematic weeds before and after the adoption of GR cotton. Similar percentages were reported for morningglory and pigweed species before and after adoption. Problems with sicklepod, however, were reported less frequently after adoption of GR cotton. In GR corn, although results for morningglory are not reported, percentages decreased for sicklepod and pigweed after adoption.

In Indiana, a survey of corn and soybean growers was conducted in 2003 to identify the most troublesome winter annuals and summer annuals/perennials (Gibson et al. 2005). The most problematic winter annuals included horseweed and three other species. Problem summer annuals included giant ragweed (*Ambrosia trifidia* L.), common lambsquarters (*Chenopodium album* L.), and velvetleaf. With the exceptions of horseweed and giant ragweed, the majority of these species are currently not listed as resistant to glyphosate (Heap 2011). Indiana was one of the first states in which GR giant ragweed was confirmed; however, Gibson et al. (2005) reported that giant ragweed had been previously listed as troublesome in preceding surveys. Indiana was also one of the earliest states in which GR horseweed was confirmed (Heap 2011), and when Gibson et al. (2005) compared their results with previous weed surveys, horseweed had not been historically listed as one of the most troublesome weeds.

Culpepper (2006) surveyed weed scientists in 11 geographically-dispersed states to examine how weed population dynamics changed after widespread adoption of the GR crops corn, cotton, and soybean. Scientists identified the weed species in each GR crop that were increasing in population. No shifts were reported in GR corn, although this was considered to be due to the limited time of use for this technology. For both cotton and soybean, morningglory was the most common response. *Commelina* species were reported for both crops also, in addition to *Amaranthus* species for cotton, and common lambsquarters and waterhemp (*Amaranthus tuberculatus* (Moq.) Sauer.) for soybean. Shifts were not solely associated with glyphosate, but were the result of reduced tillage and decreased use of residual herbicides—activities that have been shown to be concurrent with adoption of GR cropping systems.

Kruger et al. (2009) also reported that shifts in weed populations were occurring. Their data suggested that with the exception of pigweed and morningglory, many weeds remained problematic but to a lesser degree after the introduction of GR cropping systems. The most commonly mentioned weeds were similar to those previously stated and showed regional differences such as common ragweed in Indiana and sicklepod in the cotton-growing states Mississippi and North Carolina.

In 2005, university weed scientists developed a grower survey to understand grower perceptions of weed populations and problematic weed species before and after adoption of Roundup Ready™ cropping systems (Shaw et al. 2009). Approximately 1,200 growers in six states (approximately 200 per state in Iowa, Illinois, Indiana, Mississippi, North Carolina, and Nebraska) were surveyed by telephone in the winter from 2005 to 2006. Key findings reported in regard to problem weeds included (from Kruger et al. 2009):

- Over all tillage systems, 44 to 66% of the growers indicated that the weed pressure decreased, 31 to 50% indicated that it remained the same, and 1 to 6% indicated increased weed pressure after adopting GR crops.
- None of growers surveyed indicated that weed pressure was heavy when fields were in GR crops for more than 5 yr.
- Most weed species, except for morningglory and pigweed species, present before the introduction of GR crops continued to be problem weeds, but to a reduced degree after adopting GR cropping systems.

The objective of this paper is to report information from a follow-up survey to that conducted in 2005, specifically to determine the current state of problem weeds in GR corn, cotton, and soybean cropping systems and to evaluate if these weed species represent a shift from historically problematic weeds. At the time of the first survey, in most agronomic areas of the United States awareness and proliferation of GR weeds was not as cosmopolitan as is the case now. In the last 5 yr, increased prevalence of GR weeds will have undoubtedly brought changes in grower awareness. In addition, a number of educational efforts by university extension programs have been developed to affect grower implementation of herbicide resistance management practices. However, as noted from previous surveys, the GR cropping system provides such a simple and economically advantageous program that it is extraordinarily difficult to change grower practices. The information collected from the follow-up survey will show the current status of problematic weeds and their importance in modern GR farming operations. This information can be used to highlight any weed population shifts that may be occurring and indicate areas of future weed management concern.

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Methods and Materials

A 2005 telephone survey was developed by weed scientists from a geographically diverse mix of universities in the United States including Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina. A grower poll was conducted in these states, which were selected to ensure a mix of cropping practices and environments, and represent major areas of GR cropping acreage. Complete details of this initial Benchmark Survey are reported by Shaw et al. (2009). Other publications generated from the 2005 Benchmark Survey include targeted papers about specific aspects of the survey including herbicide use patterns (Givens et al. 2009a), tillage trends (Givens et al. 2009b), grower attitudes (Johnson et al. 2009), management practices (Givens et al. 2011), and problematic weeds and changes in weed pressure (Kruger et al. 2009).

After modifying the initial Benchmark Survey, it was readministered by Market Probe (formerly Marketing Horizons) from December 10, 2009 to January 21, 2010. In the current telephone survey, a random selection of almost 1,300 growers was selected from a list of all growers who signed an agreement with Monsanto Agricultural Products Company to use GR crops (Roundup Ready™). An additional 350 growers who participated in the original 2005 Benchmark Survey (Shaw et al. 2009) were also included, resulting in a total of almost 1,650 growers for the current survey. Growers had to meet certain eligibility requirements to participate in the survey. These included: (1) be actively involved in farming, (2) be responsible for the decisions concerning the seeds, traits, and herbicides purchased for their operation, (3) plant a minimum of 101 ha of corn, cotton, or soybean in 2009, and (4) plant the GR trait for a minimum of 3 yr. The minimum farm size ensured that survey participants were engaged full-time in production agriculture and derived a significant portion of their livelihood from farming. Producers were disqualified from participating in the survey if anyone in their household worked for a farm chemical manufacturer, distributor, or retailer, or if they worked for a seed company other than as a farmer/dealer to avoid conflicts of interest.

The 2010 survey was conducted using growers from 22 states where corn, cotton, or soybean are the predominant crops produced. The 2010 survey represents a more inclusive national cross-section of growers. This was done to better delineate differences that might exist in grower attitudes and perceptions on the basis of crop production region. For some analyses reported, the participating states were grouped into three regions: South, East, and West (Figure 1).

The survey contained four sections designed to focus on different aspects of the issues involved with GR weeds and cropping systems based on GR technologies. The first section of the survey was used to subsequently divide growers who responded into groups on the basis of cropping system for the other survey sections. Current and past crop history, including experience with GR crops, was addressed. Weed population density, weed species shifts, and tillage practices on a specific field selected by the grower are covered in the second section of the survey. This section also included questions that asked growers to indicate specific weeds with which they had experienced control problems, which is presented in this paper. Growers were asked about their herbicide use practices

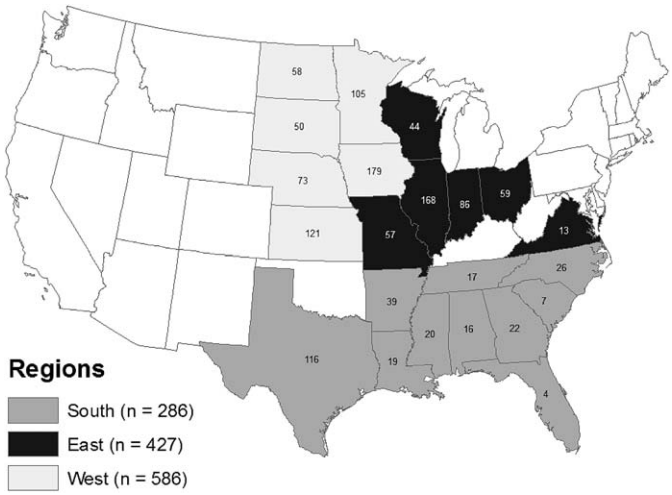


Figure 1. Geographic distribution of regions for the 2010 Benchmark Survey with totals for survey respondents in each state and region.

in the third section. Questions focused on current and previous herbicide regimes, application timings, and rates; glyphosate and non-glyphosate chemical applications were included. Growers were asked specifically to highlight any changes in weed management practices they had made in the previous 3 yr. The final section focused on grower attitudes and awareness related to GR weeds and management practices specific to GR weeds. Growers were asked about their experiences (if any) with GR weeds and what weed management practices they personally were using to manage or prevent GR weeds in their cropping systems. This section allowed growers to specifically identify weeds they were having problems with and were known by the growers to have evolved resistance to glyphosate.

Nine cropping systems were designated for the survey. These included: continuous GR soybean, continuous GR cotton, continuous GR corn, GR corn/GR soybean rotation, GR cotton/GR soybean, GR cotton/GR corn, GR soybean/non-GR crop rotation, GR corn/non-GR crop rotation, and GR cotton/non-GR crop. A grower was placed into one or two of these systems, depending on their specific, predominant cropping programs. For the portions of the survey presented, respondents were asked yes/no questions as a screen and then given open-ended questions as a follow-up. Growers were also asked to evaluate specific issues on a scale of 1 to 10, with 1 representing the worst possible rating.

Data for the overall survey were analyzed using McNemar's test (Conover 1999) for the yes/no questions, and *t* tests and frequency counts for questions with scaled answers. For the growers who were surveyed in the 2005 Benchmark Survey and the current survey, *t* tests were used to compare answers between the two surveys. To compare differences between regions, Kruskal–Wallis testing was performed (Conover 1999). All analyses were performed at the $\alpha = 0.05$ significance level.

Results and Discussion

The average producer surveyed in a GR soybean system reported that he has been in this system for 9 yr. Other

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Table 1. Grower assessment of specific weed population density ratings by cropping system on a 1 to 10 scale where 10 represents the heaviest population density.

Cropping system	Light (1–4)	Moderate (5–6)	Heavy (7–8)	Very heavy (9–10)
	% of growers			
Continuous GR[a] soybean (n = 152)	59	12	22	7
Continuous GR corn (n = 222)	73	14	9	3
Continuous GR cotton (n = 97)	40	35	11	11
GR corn/GR coybean (n = 618)	70	19	10	1
GR cotton/GR soybean (n = 33)	37	33	24	6
GR cotton/GR corn (n = 22)	55	36	9	-
GR soybean/non-GR crop (n = 381)	63	25	10	1
GR corn/non-GR crop (n = 169)	63	27	7	2
GR cotton/non-GR crop (n = 70)	43	40	11	4

[a] Abbreviation: GR, glyphosate-resistant.

continuous GR single-crop systems posted averages of 7 yr for cotton and 5 yr for corn growers. Kruger et al. (2009) reported that no growers who had used GR cropping systems for 5 yr or more felt they had "heavy" weed pressure. In the 2005 Benchmark Survey, it was noted that the average number of years producers stayed in a continuous GR soybean and continuous GR cotton system was 5 yr for both (Shaw et al. 2009). The concern was raised in the results of the 2005 survey that this behavior was typical of a situation that facilitates the evolution of glyphosate resistance and could be indicative of a long-term problem with GR weeds. However, a long-term problem was not indicated with regard to weed pressure. Growers were asked to rate weed pressure in their selected fields on a scale of 1 to 10, where 10 represents very heavy weed pressure. The majority of growers reported that their weed pressure was light (1 to 4), and small percentages reported very heavy pressure (9 to 10) (Table 1). Growers were more likely to report light weed pressure rather than heavy weed pressure, regardless of cropping system. Thus the finding indicates that the same risky behavior identified by Shaw et al. (2009) continued but concurs with Kruger et al. (2009) because low weed pressures are reported for GR cropping systems.

Growers were then asked which specific weeds were currently the biggest problem(s) in their selected field(s) that represented one of the nine cropping systems. The largest number of growers fell into the GR corn/GR soybean rotation. Other large cropping systems included GR soybean/non-GR crop, and continuous GR corn. Two categories had limited growers, limiting their usefulness for analysis. These were GR cotton/GR soybean and GR cotton/GR corn. Growers were allowed to provide multiple answers for each of their represented cropping systems (Table 2). GR cotton growers most often reported pigweed regardless of whether the cotton was continuous or rotated with other crops. The second most frequent response was morningglory. Continuous GR corn growers reported foxtail (*Setaria* spp.) and velvetleaf among their most troublesome weeds. When GR corn was used in a rotation, foxtail remains among the most frequent responses, but waterhemp replaced velvetleaf. Continuous GR soybean growers frequently reported problems with pigweed, as did GR soybean growers who rotated with GR cotton. However, when GR soybean was rotated with other crops, growers more frequently cited foxtail, waterhemp, and in the case of a rotation with GR cotton, horseweed.

These results represent substantial increases in the responses for pigweed among growers of continuous GR soybean and cotton (Table 3). Other major changes include decreases in response for morningglory among these same groups, an increase for waterhemp in GR soybean alone and rotated with GR corn, and an increase in responses for common lambsquarters in GR soybean–GR corn rotations.

In addition to listing their current problematic weeds, growers were asked which weeds had been their biggest challenge(s) in weed pressure since they began using the current cropping system on their selected fields. For many cropping systems, growers responded that they had experienced no challenges (Table 4). Growers in continuous GR cotton reported that pigweed was their biggest challenge and this extended into rotations containing GR cotton and other crops. In the rotation of GR cotton and non-GR crop, the highest percentages of responses were for morningglory and pigweed.

In the awareness portion of the survey, growers were asked another series of questions specifically related to GR weeds. This portion of the survey was also given to the 350 growers who previously participated in the 2005 Benchmark Survey. Growers were asked first if they were aware of any specific weeds in their county and state with documented resistance to glyphosate. If a grower answered yes to either, they were asked to list the specific weeds. The most frequent response for both

Table 2. Grower assessment of current problem weeds reported by cropping system.

Cropping system	Pigweed	Morningglory	Waterhemp	Horseweed	Foxtail	Lambsquarters	Velvetleaf	Ragweed
	% of growers[a]							
Continuous GR[b] soybean (n = 152)	29	14	18	17	4	3	4	8
Continuous GR corn (n = 222)	16	5	18	1	23	16	22	17
Continuous GR cotton (n = 97)	56	20	-	14	2	1	1	-
GR corn/GR soybean (n = 618)	10	5	32	10	26	21	20	20
GR cotton/GR soybean (n = 33)	61	12	6	30	6	3	-	-
GR cotton/GR corn (n = 22)	46	23	-	14	-	-	-	-
GR soybean/non-GR crop (n = 381)	12	6	22	9	27	16	14	18
GR corn/non-GR crop (n = 169)	15	4	20	4	21	14	13	11
GR cotton/non-GR crop (n = 70)	46	21	1	7	-	-	-	1

[a] Growers were allowed to provide multiple answers, thus totals do not sum to 100%.

[b] Abbreviation: GR, glyphosate-resistant

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Table 3. Grower assessment of changes in problem weeds between 2005 and 2010 Benchmark Surveys reported by cropping system.[a]

Cropping system	Pigweed	Morningglory	Waterhemp	Foxtail	Lambsquarters	Velvetleaf	Ragweed
	% of growers[b]						
Continuous GR[c] soybean (n = 152)	+20	−10	+10	−5	0	−2	−2
Continuous GR cotton (n = 97)	+31	−27	0	0	0	0	0
GR corn/GR soybean (n = 618)	+6	+1	+12	+6	+16	+4	+7
GR soybean/non-GR crop (n = 381)	+8	−2	+7	+2	+9	−4	+3
GR corn/non-GR crop (n = 169)	+7	0	+7	+1	+3	0	0

[a] Not all cropping systems were considered in the 2005 survey (Kruger et al. 2009), nor was horseweed reported.

[b] Growers were allowed to provide multiple answers, thus totals do not sum to 100%.

[c] Abbreviation: GR, glyphosate-resistant.

state (39%) and county (41%) was horseweed. *Amaranthus* spp., including pigweed and waterhemp, were the next most frequent responses in both categories. Awareness of weeds was influenced by regional differences in weed spectrum. Growers in the West and East regions were more likely to list horseweed at the top of the list, whereas pigweed dominated in the South by a greater than 30% margin over horseweed.

When the 2010 Benchmark Survey answers from the subset of 350 growers who participated in both surveys were compared as a block against the answers for the core group of 1,299 growers, no differences existed for horseweed or pigweed in the percentage of growers aware of these weeds with GR biotypes in their state. When the answers are compared between 2005 and 2010 for only the 350 growers who participated in both Benchmark Surveys, horseweed (39%), pigweed (21%), and waterhemp (23%) all had significant increases in the percentages of responses for the growers aware of these weeds in their state. The question regarding GR weeds in a grower's county was not included in 2005, so no comparisons can be made.

Growers were asked if they had personally experienced any GR weeds on their farm. For respondents in the East and West regions, average hectarage planted was similar for soybean (214,187 ha) and corn (222,207 ha). In the South, average hectarage was similar for cotton (190 ha) and soybean (192 ha), with smaller hectarage devoted to corn (116 ha). If a grower answered in the affirmative, they were asked to list the specific weeds. Growers in the South overreport the presence of GR weeds on their farm when compared with East and West regions (53, 28, and 23%, respectively, $P < 0.05$). Growers in the South are more likely to report problems with pigweed and horseweed. Growers in the East and West regions report horseweed and waterhemp, while seldom reporting pigweed. In the South region, much attention has been given to the significant problem posed by GR Palmer amaranth, which may account for the high percentages reported in the survey. The myriad concerns over how to manage this species (Price et al. 2011) underscore the need to monitor species shifts and educate growers on alternative strategies that reduce selection pressure.

When the 2010 answers from the subset of 350 growers to this question were compared as a block against the answers for the core group of 1,299 growers, significant differences ($P < 0.05$) existed for horseweed, pigweed, and waterhemp for the percentage of growers reporting these weeds as GR on their farm. When only the responses of the 350 growers who participated in both Benchmark Surveys are compared between 2005 and 2010, significant increases are seen in percentages of growers with GR horseweed (19%), pigweed (11%), and waterhemp (4%) on farm. These figures indicate that a shift to these species is occurring.

A lingering question posed in the 2005 Benchmark Survey regarded the fate of weeds such as giant foxtail (*Setaria faberi* Herrm.) and velvetleaf and whether they would evolve resistance to glyphosate or merely capitalize on the niche created by current management systems in GR crops (Kruger et al. 2009). This issue could be examined for any of the weeds mentioned here. Morningglory and pigweed have been a long-term economic problem in the crops examined here, even from before the time of introduction of GR technology. Compared with results from the 2005 Benchmark Survey, an increase ($P < 0.05$) in awareness of GR pigweed and other GR weed species is occurring.

Horseweed appears to have emerged after introduction of GR cropping systems, and continues to present problems for

Table 4. Grower assessment of the biggest challenges in weed pressures reported by cropping system.

Cropping system	No challenges	Pigweed	Morningglory	Waterhemp	Horseweed	Foxtail	Velvetleaf	Ragweed
	% of growers[a]							
Continuous GR[b] soybean (n = 152)	20	18	5	11	12	2	2	6
Continuous GR corn (n = 222)	26	5	5	10	1	7	6	9
Continuous GR cotton (n = 97)	10	34	17	-	10	-	-	-
GR corn/GR soybean (n = 618)	25	4	3	16	6	-	-	9
GR cotton/GR soybean (n = 33)	9	48	9	3	18	-	-	-
GR cotton/GR corn (n = 22)	18	23	23	-	18	-	-	-
GR soybean/non-GR crop (n = 381)	23	6	2	14	5	5	-	9
GR corn/non-GR crop (n = 169)	21	2	3	11	3	4	-	7
GR cotton/non-GR crop (n = 70)	17	23	27	-	3	-	-	-

[a] Growers were allowed to provide multiple answers, thus totals do not sum to 100%.

[b] Abbreviation: GR, glyphosate-resistant.

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some growers. Conversely, problems with sicklepod appear to have lessened after the adoption of GR cropping systems as numbers have declined to the point of nonreporting in the 2010 Benchmark Survey. *Commelina* spp., which were thought to be poised to become serious problems (Culpepper 2006), are absent from the answers collected from growers in the 2010 Benchmark Survey. Selection pressure appears to have shifted the weed spectra away from these species in favor of current species of interest in weed science such as horseweed and *Amaranthus* spp.

Although awareness of GR weeds has increased and a trend can be shown for specific weeds continually creating problems for growers, these problems appear to be lessened by the use of GR cropping systems over time. Growers in this survey still rated their overall weed pressure as light. Kruger et al. (2009) reported that no growers who had used GR cropping systems for 5 yr or more felt they had heavy weed pressure. Foxtail and velvetleaf continue to be a problem; however, they have not evolved resistance to glyphosate, indicating that Kruger et al. (2009) may be correct in their assessment that the problematic nature of these particular species is a function of available ecological niche only. However, growers are particularly sensitive to heightened problems with the pigweed complex, no doubt in large part because of the high-profile problems being encountered with Palmer amaranth and waterhemp. Growers in this survey indicated that the *Amaranthus* complex was a growing problem, particularly in continuously cropped soybean and cotton. Scientists are working to elucidate the mechanism(s) of action within the amaranths; all indications are that multiple mechanisms may be at play, which would indicate tremendous potential for further resistance evolution. Educating growers about best management practices may help in the control of these species by altering the ecological niche without the evolution of glyphosate resistance resulting from the continual selection pressure from recurrent glyphosate use.

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Literature Cited

Conover, W. J. 1999. Practical Nonparametric Statistics. 3rd ed. New York: John Wiley and Sons. 592 p.

Culpepper, A. S. 2006. Glyphosate-induced weed shifts. Weed Technol. 20:277–281.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065–1070.

Givens, W. A., D. R. Shaw, W. G. Johnson, S. C. Weller, B. G. Young, R. G. Wilson, M.D.K. Owen, and D. Jordan. 2009a. A grower survey of herbicide use patterns in glyphosate-resistant cropping systems. Weed Technol. 23:156–161.

Givens, W. A., D. R. Shaw, G. R. Kruger, W. G. Johnson, S. C. Weller, B. G. Young, R. G. Wilson, M.D.K. Owen, and D. Jordan. 2009b. Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol. 23:150–155.

Givens, W. A., D. R. Shaw, and M. E. Newman. 2011. Benchmark study on glyphosate-resistant cropping systems in the USA. III. Grower awareness, information sources, experiences, and management practices regarding glyphosate-resistant weeds. Pest Manag. Sci. 67:758–770.

Gressel, J. and L. A. Segel. 1990. Modeling the effectiveness of herbicide rotations and mixtures as strategies to delay or preclude resistance. Weed Technol. 4:186–198.

Heap, I. 2011. The International Survey of Herbicide-Resistant Weeds. http://www.weedscience.com. Accessed: October 22, 2011.

James, C. 2009. Global Status of Commercialized Biotech/GM Crops: 2009. ISAAA Brief No. 41. Ithaca, NY: ISAAA. http://www.isaaa.org/Resources/publications/briefs/41/default.asp. Accessed: October 11, 2010.

Johnson, W. G., M.D.K. Owen, G. R. Kruger, B. G. Young, D. R. Shaw, R. G. Wilson, J. W. Wilcut, D. L. Jordan, and S. C. Weller. 2009. U.S. farmer awareness of glyphosate-resistant weeds and resistance management strategies. Weed Technol. 23:308–312.

Kruger, G. R., W. G. Johnson, and S. C. Weller, 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 Technol. 23:162–166.

Price, A. J., K. S. Balkcom, S. A. Culpepper, J. A. Kelton, R. L. Nichols, and H. Schomberg. 2011. Glyphosate-resistant Palmer amaranth: a threat to conservation tillage. J. Soil Water Conserv. 66:265–275.

Shaw, D. R., W. A. Givens, and L. A. Farno, 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 Technol. 23:134–149.

Webster, T. M. and G. E. MacDonald. 2001. A survey of weeds in various crops in Georgia. Weed Technol. 15:771–790.

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