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In 2010, a grower survey was administered to 1,299 growers in 22 states to determine changes in weed management in the United States from 2006 to 2009. The majority of growers had not changed weed management practices in the previous 3 yr; however, 75% reported using weed management practices targeted at glyphosate-resistant (GR) weeds. Growers were asked to rate their efforts at controlling GR weeds and rate the effectiveness of various practices for controlling/preventing GR weeds regardless of whether they were personally using them. Using the herbicide labeled rate, scouting fields, and rotating crops were among the practices considered by growers as most effective in managing GR weeds. Sixty-seven percent of growers reported effective management of GR weeds. Between the 2005 and 2010 Benchmark surveys, the frequency of growers using specific actions to manage GR weeds increased markedly. Although the relative effectiveness of practices, as perceived by growers, remained the same, the effectiveness rating of tillage and the use of residual and POST herbicides increased.

Nomenclature: Glyphosate; herbicide; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; soybean, *Glycine max* (L.) Merr.

Key words: Glyphosate-resistant crops, glyphosate resistance management, grower survey, herbicide mode of action.

En 2010, se practicó una encuesta a 1299 productores en 22 estados para determinar los cambios en el manejo de malezas en los Estados Unidos de 2006 a 2009. La mayoría de los productores no había cambiado sus prácticas en el manejo de malezas los tres años anteriores; sin embargo, el 75% reportó el uso de prácticas dirigidas a las malezas resistentes a glyphosate (GR). Se les pidió a los productores evaluar sus esfuerzos en el control de malezas GR y calificar la efectividad de varias prácticas para controlar/prevenir malezas GR, sin importar si ellos las estaban usando personalmente. Usar la dosis recomendada, muestrear los campos y rotar los cultivos estuvieron entre las prácticas consideradas por los productores como las más eficaces en el manejo de malezas GR. El sesenta y siete por ciento de los productores reportó un manejo efectivo de malezas GR. Entre las encuestas de referencia de 2005 y 2010 se incrementó notablemente la frecuencia del uso por parte de los productores de acciones específicas para manejar malezas GR. Aunque la percepción de los productores de la efectividad relativa de las prácticas permaneció igual, se incrementó la calificación de la efectividad del uso de labranza y de herbicidas residuales y pos emergentes.

With 21 weed species worldwide having evolved resistance to glyphosate in the past two decades (Heap 2011), glyphosate resistance management has become a major focus of the weed science community, growers, and their advisers. The commercialization of glyphosate-resistant (GR) crops allowed growers to make major changes in weed management programs, which included reducing the diversity of herbicide use and tillage intensity. The simplicity and convenience of weed management accounts for much of the popularity of GR crops, making this technology the most rapidly adopted crop trait in history (Johnson et al. 2009).

Frisvold et al. (2009) conducted a survey to examine grower adoption of best management practices (BMPs) in 2007. Commodity groups, university extension services, and chemical companies have recommended various BMPs for delaying and preventing evolution of GR weeds. In their study, 10 BMPs were considered, and seven of these BMPs were practiced by

71% or more of growers included in the survey, and these same seven BMPs were consistent between crop commodities. Supplemental tillage and cleaning equipment were not consistently used by growers as practices to manage GR weeds, whereas correct herbicide rates and scouting were frequently reported as practiced.

Sammons et al. (2007) reviewed biochemical aspects of resistance to determine what practices would constitute effective stewardship of glyphosate use. The key principles included starting with a weed-free field, early control of weeds, inclusion of other herbicides and cultural practices, using the full manufacturer's recommended rate, and controlling weed escapes. These practices were also recommended by Gustafson (2008), who derived his recommendations from computer modeling and field tests of glyphosate-use sustainability. Additional practices identified by Gustafson (2008) on the basis of modeling and tests included: use of crop rotation, cleaning equipment between fields, and starting with weed-free seed.

The importance of a diverse weed management program was underscored by modeling (Werth et al. 2008). A crop management plan was developed for GR cotton in Australia with restrictions on rates and timing of glyphosate applications. The plan also required that any weed escapes be treated with alternative practices before seed development. Barnyardgrass

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(*Echinochloa crus-galli* (L.) Beauv.) and liverseed grass (*Urochloa panicoides* Beauv.) were selected as case studies for modeling. Currently, of the two species, only liverseed grass has documented GR biotypes (Heap 2011). Werth et al. (2008) reported that weed management strategy had a major influence on the rate of glyphosate resistance evolution, and with careful selection of management tactics, glyphosate resistance could be avoided for 30 yr or longer in this GR cotton production system. Addition of a POST graminicide or the use of a soil-applied residual herbicide at planting and again at mid-season delayed glyphosate resistance evolution by as much as 2 yr, even when substantial applications of glyphosate were included in the weed management program.

The objectives of this paper were to examine grower changes in management as they attempt to control GR weeds. An attempt was made to understand which practices growers believe to be the most effective at managing the evolution of GR weeds, to understand why growers preferentially choose some practices and not others. These objectives were part of a much larger study to understand grower attitudes, awareness, and resultant weed management practices with regard to managing glyphosate resistance in weeds.

Methods and Materials

A 2005 telephone survey was developed through collaboration among weed scientists from Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina. The survey was used for a grower poll in these states, which were selected to ensure a mix of cropping practices and environments. These states also represent major areas of GR crop production. Complete details of this initial survey are reported in Shaw et al. (2009). Focused papers include herbicide use patterns (Givens et al. 2009a), tillage trends (Givens et al. 2009b), problematic weeds (Kruger et al. 2009), and grower attitudes (Johnson et al. 2009). The most relevant precursor to the current paper (Givens et al. 2011) focuses on management practices and information sources of growers dealing with GR weeds.

With slight modifications, the survey (Prince et al. 2012) was readministered by Market Probe (formerly Marketing Horizons) from December 10, 2009 to January 21, 2010. A list of growers who signed an agreement to use GR crops (Roundup Ready™) was obtained from Monsanto Agricultural Products Company, and from this list a pool of 1,299 growers was selected at random. An additional 350 growers who participated in the 2005 Benchmark Survey (Shaw et al. 2009) were also included, resulting in a total of almost 1,650 growers for the current survey. Eligibility for growers to participate in the survey required that they: (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 crop 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. To avoid conflicts of interest, 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.

The growers in the 2010 survey were from 22 states where corn, cotton, and soybean are predominant crops produced. The increased number of states included in the 2010 survey represents a significant change from the 2005 Benchmark Survey. The 2010 survey was broadened to provide a more inclusive national cross-section of growers, and to better delineate differences that might exist in grower attitudes and perceptions on the basis of crop production region. However, some growers originally interviewed in the 2005 Benchmark Survey were also resurveyed to statistically assess changes in perceptions among these growers since the 2005 Benchmark Survey was conducted (Shaw et al. 2009). For some analyses of the 2010 survey, the states were grouped into three regions (Figure 1): South, East, and West.

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 addressed the current and past crop history, including experience with GR crops. The information was used to subsequently divide growers who responded into groups on the basis of cropping system for the other survey sections. The second survey section included questions about weed population density, weed species shifts, and tillage practices on a specific field selected by the grower. This section also included questions that asked growers to indicate specific weeds with which they had experienced control problems. In the third section, growers were asked about their herbicide use practices. Questions focused on current and previous herbicide regimes, application timings, and rates; glyphosate and nonglyphosate 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

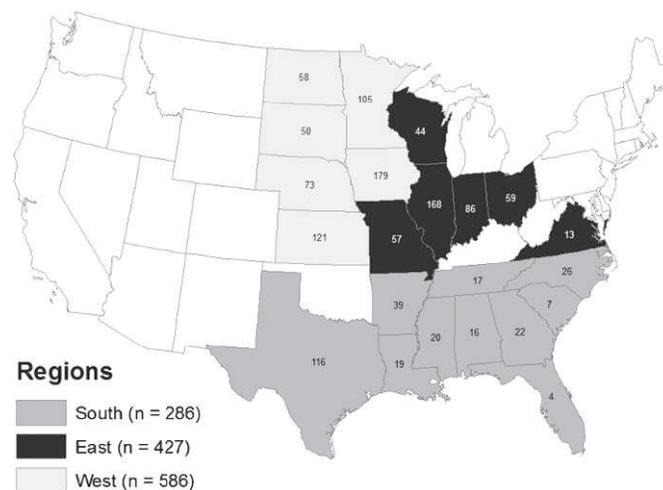


Figure 1. Geographic distribution of regions defined by survey with totals for survey respondents in each state and region.

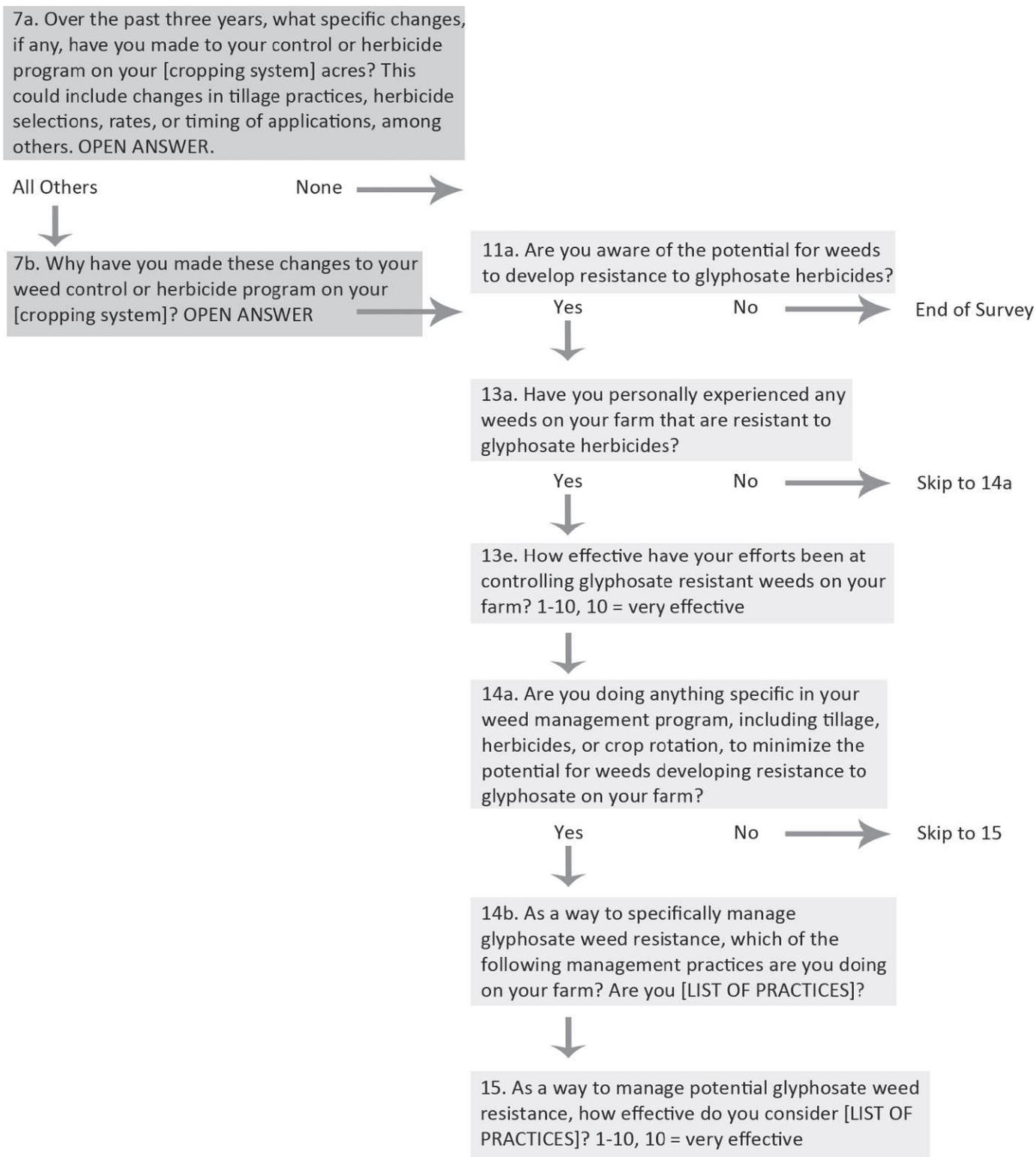


Figure 2. Survey flow for questions covered in this article.

weed management practices they personally were using to manage or prevent GR weeds in their cropping systems.

On the basis of answers from Section one of the survey, growers were placed into up to two of nine cropping system

designations. 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

Table 1. Weed management practices reported by growers as used specifically to manage glyphosate-resistant weeds.

Weed management practice	All growers			Growers who reported taking specific actions		
	Overall	With on-farm resistance	Without on-farm resistance	Overall	With on-farm resistance	Without on-farm resistance
	% of growers					
Correct herbicide rates and timing	73	86	67	99	99	99
Field scouting before and after application	70	82	65	95	96	96
Crop rotation	68	80	63	93	93	93
Control weed escapes/prevent seed set	67	75	63	92	89	94
Start with a clean field	65	77	59	88	90	88
Use multiple chemistries and a residual herbicide	61	75	54	83	87	80
Use multiple chemistries and another POST herbicide	54	72	46	74	84	68
Use preplant tillage	49	51	49	67	59	72
Rotate chemistries by year	41	50	37	56	59	55
Rotate between Roundup-ready (RR) and non-RR crop	37	45	33	51	52	49
Clean equipment between fields	28	32	26	38	37	39
Use in-crop tillage/cultivation to supplement control	22	28	20	31	32	30
Did not use management practices	27	14	32			

crop rotation, and GR cotton/non-GR crop. Respondents were asked a series of yes/no questions, and several questions in which they were asked to evaluate an issue on a Likert scale of 1 to 10, with 1 being the worst possible rating. Growers were asked a series of open-ended questions as well as questions where they selected from a predetermined list.

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 responses. For the growers who were surveyed in the 2005 Benchmark Survey and the current survey, paired *t* tests were used to compare responses for individual growers between the two surveys. Kruskal-Wallis testing (Conover 1999) was conducted to compare differences between responses in different regions. All analyses were performed at the 0.05 significance level.

Results and Discussion

Growers were asked a series of questions regarding their opinions and utilization of specific management practices for GR weed management (Figure 2). Growers were first asked if they had made any specific changes to their weed management program, whether in response to GR weeds or not. The majority of growers reported no specific changes in weed management practices. When changes were implemented, selection of herbicides and application timings were mentioned most frequently (data not presented).

Growers mentioned that changes in management were designed to achieve optimized weed control regardless of cropping systems. Issues associated with herbicide resistance were the second most frequent response across cropping systems (data not presented). This was also true for all cropping systems. A small sample of growers mentioned specific weeds such as *Amaranthus* spp. and horseweed (*Conyza canadensis* L.) as major concerns.

Growers were asked if they had GR weeds on their farms. If growers responded in the affirmative ($n = 399$), they were asked a follow-up question in which they were asked to rate the effectiveness of their efforts at controlling GR weeds on their farms. Most growers reported that they had been very

effective (25%) or somewhat effective (42%) in controlling these weeds. Twelve percent of the growers who participated in the survey reported ineffective control of GR weeds. There were no differences in effectiveness ratings when comparing geographical regions ($P = 0.10$).

All growers were asked if they were using any specific management practices to prevent the development of GR weeds or manage existing GR weeds. Overall, 73% of the growers reported that they were utilizing specific management practices targeted at GR weeds in their weed management program. No regional differences were identified. If only growers who reported that they had GR weeds on-farm were considered, the percentage of growers using specific management practices for GR weeds increased to 86%. Growers who participated in the 2005 Benchmark Survey ($n = 350$) were also asked this question in 2010. When both surveys were compared, the percentages of growers reporting specific management practices for GR weeds increased from 69% of growers in 2005 to 73% in 2010. When the responses for individual growers participating in both surveys were compared, the average frequency of growers utilizing practices to manage GR weeds increased from 67% in 2005 to 87% in 2010.

Growers were given a list of BMPs and asked if they were using any of the practices in an effort to control or prevent GR weeds. The three most common practices for controlling GR weeds for all growers were: (1) using the correct herbicide rates (73% of growers), (2) scouting fields (70%), and (3) rotating crops (68%) (Table 1). These results were similar to Johnson and Gibson (2006), who found that less than 12% of growers were unwilling or unsure about scouting fields. Johnson and Gibson (2006) also reported that 38% of growers attributed resistance to improper herbicide application and timing, and not repeated use of glyphosate. This may account for the large percentage of growers in this study relying on correct herbicide rates to control GR weeds. When only the growers reporting glyphosate resistance on-farm were considered, the percentage of growers using these management practices was higher. When only the set of growers who reported using specific management practices targeted at GR weeds was considered, the most commonly mentioned

Table 2. Grower perception of effectiveness for commonly used practices to manage glyphosate-resistant weeds, 2005 and 2010 survey responses.

Weed management practice	Average rating		Significance level
	2010	2005	
Correct herbicide rates and timing	8.61	8.61	0.37
Crop rotation	7.45	7.31	0.64
Use multiple chemistries and a residual herbicide	7.68	6.95	< 0.05
Use multiple chemistries and another POST herbicide	7.49	6.87	< 0.05
Rotate chemistries by year	7.15	7.18	0.49
Rotate between Roundup-ready (RR) and non-RR crop	6.54	6.76	< 0.05
Use in-crop tillage/cultivation to supplement control	6.28	5.49	< 0.05

practices were the same. Moreover, if the practices are ranked by percentage, the relative rank is the same between growers who are using specific management practice for GR weeds and those who are not. Almost 30% of growers surveyed did not use any tactics to specifically control GR weeds.

Growers were also asked to evaluate the effectiveness of the common practices used to manage GR weeds (listed in Table 1) on a scale of 1 to 10. According to growers, the most effective practice for controlling GR weeds was using the correct label rate; 62% of growers rated this practice either a 9 or 10. By comparison, the next practices that received the most 9 and 10 ratings were rotating crops (37%) and rotating herbicide chemistries (34%). These practices were also ranked high in the 2005 Benchmark Survey where using the correct label rate was the most highly rated practice, followed by rotating crops and rotating chemistries (no significant difference was seen between these two practices) (Givens et al. 2011).

The effectiveness ratings from the 2005 Benchmark Survey were compared against the results from the 2010 survey (Table 2). These three commonly used practices—using the correct label rate, rotating crops, and rotating chemistries—are the only practices for which both paired and nonpaired *t* tests resulted in no significance. This indicates that the perceptions of effectiveness by the growers who participated in both surveys have not changed for these three practices, but have changed for all other practices considered. Recent efforts to educate growers about the importance of integrating weed management tactics other than glyphosate for management of GR weeds may have resulted in changed perceptions about the effectiveness of key management practices that weed scientists believe are most effective for controlling GR weeds and delaying evolution of glyphosate resistance. The practices for which perceived effectiveness increased from 2005 to 2010 include using POST and residual herbicides and using tillage. These results agree with a 2006 survey (Foresman and Glasgow 2008) that concluded that when faced with glyphosate resistance, growers indicated that they would rotate herbicides and use tank mixes, in addition to increasing tillage to manage GR weeds.

Differences between regions were not significant for any of the survey questions considered in this portion of the 2010 Benchmark Survey, suggesting that adoption of broad-spectrum, long-term glyphosate resistance management practices may be possible. Johnson and Gibson (2006) showed that many growers were willing to initiate various weed management practices targeted at GR weeds. However, grower perceptions that herbicide resistance was not the result of repeated use of a herbicide or herbicides with the same mode of

action indicated that education may be required to convince growers of the merit of adopting alternative practices to control herbicide-resistant weeds.

In general, the results of the 2010 Benchmark Survey suggested that many growers were using practices targeted specifically at preventing or managing GR weeds, but these practices were not new introductions to their weed management plans. Many growers felt their practices were effectively managing GR weeds. Unfortunately, the practices for GR weed control deemed effective by growers are often not the most preferred practices according to weed scientists. However, grower perception of the effectiveness of practices recommended by the weed science community is increasing. With growers indicating that they were making few changes to their weed management plans and a strong belief that these practices are effective at controlling GR weeds, the burden to present growers with the best information possible and to justify the inclusion of any new glyphosate resistance management practices aimed at GR weed control is on the weed science community.

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