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Benchmark Study: III. Survey on Changing Herbicide Use Patterns in Glyphosate-Resistant Cropping Systems

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Approximately 1,300 growers from 22 states were surveyed during 2010 to determine herbicide use. Cropping systems included continuous glyphosate-resistant corn, cotton, and soybean, and various combinations of these crops and rotations with non–glyphosate-resistant crops. The most commonly used herbicide for both fall and spring applications was glyphosate followed by synthetic auxin herbicides. Herbicide application in spring was favored over application in the fall. The percentage of growers in a glyphosate-only system was as high as 69% for some cropping systems. Excluding glyphosate, the most frequently used herbicides included photosystem II, mitotic, and protoporphyrinogen oxidase inhibitors. A higher percentage of growers integrated herbicides other than glyphosate during 2010 compared with 2005. Extensive educational efforts have promoted resistance management by increasing the diversity of herbicides in glyphosate-resistant cropping systems. However, a considerable percentage of growers continued use of only glyphosate from the period of 2005 to 2010, and this practice most likely will continue to exert a high level of selection for evolved glyphosate-resistant weed species.

Nomenclature: Glyphosate; 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, aproximadamente 1,300 agricultores en 22 estados fueron encuestados, para determinar el uso de herbicidas. Los sistemas de cultivo incluyeron la siembra continua de maíz, algodón y soya resistentes al glifosato, así como también, varias combinaciones de estos cultivos y rotaciones con cultivos no resistentes al glifosato. El herbicida más comúnmente usado para las aplicaciones de otoño y primavera fue glifosato seguido por herbicidas auxinas sintéticas. La aplicación de herbicidas en primavera fue más frecuentemente usada que la aplicación en el otoño. El porcentaje de agricultores usando un sistema de solo glifosato fue tan alto como 69% para algunos sistemas de cultivo. Excluyendo al glifosato, los herbicidas más frecuentemente usados incluyeron fotosistema II, mitóticos e inhibidores de la protoporfirinogen oxidasa. Durante 2010 en comparación con 2005, un mayor porcentaje de agricultores integraron a sus sistemas otros herbicidas además del glifosato. Extensos esfuerzos educativos han promovido el manejo de resistencia al incrementarse la diversidad de herbicidas en los sistemas de cultivos resistentes al glifosato. Sin embargo, un porcentaje considerable de agricultores continuó usando solamente glifosato durante el período de 2005 a 2010, y ésta práctica muy probablemente continuará ejerciendo un alto nivel de selección de especies de malezas evolucionadas resistentes al glifosato.

The introduction of glyphosate-resistant (GR) crops, the most rapidly adopted crop trait in history, allowed growers to manage weeds at lower cost in a simplified weed management system. These advantages have led to a dramatic change in the use pattern for glyphosate since 1996, when GR crops first became available (Duke and Powles 2009). A decade later, Young (2006) found a dramatic increase in the use of glyphosate in soybean and cotton production, but not in corn production since adoption rates for GR corn were slower than those of GR soybean and cotton (Dill et al. 2008). Corn producers continued to rely on atrazine (Dill et al. 2008), and the necessity for PRE herbicides (Gianessi 2008) may have contributed to less use of glyphosate in GR corn. Gianessi (2008) reported no major changes in the number of active ingredients applied to corn from 2001 to 2006 and a stable price for traditional corn herbicides such as atrazine, which may also have preserved a lower reliance on glyphosate.

In contrast to corn production, glyphosate applications on GR soybean have almost completely replaced other herbicides as a component of weed management (Young 2006). Young (2006) reported fewer soil-applied residual herbicides and greater reliance on total POST applications of glyphosate. Scott and VanGessel (2007) reported that 57% of 213 grower respondents in Delaware during 2000 to 2004 had increased reliance on glyphosate. A 2003 survey of Indiana growers indicated that glyphosate was the only herbicide applied on 74% of GR soybean (Johnson et al. 2007). In a national survey of growers during 2007, soybean growers reported using multiple herbicides in less than 50% of their applications (Hurley et al. 2009).

Young (2006) reported the average number of unique herbicide modes of action (MOAs) was consistent with previous years for growers in GR cotton production; however, glyphosate still became the herbicide applied to the greatest percentage of hectares by 2000. Dill et al. (2008) reported that 65 to 70% of GR cotton hectares received herbicide treatments with different MOAs. Cotton growers in a 2007 national survey reported using multiple chemistries in as

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much as 75% of their applications (Hurley et al. 2009). Based on a survey of weed scientists in the United States, Culpepper (2006) concluded that growers reduced or eliminated residual herbicides in cotton, leading to an increase of problematic annual grasses and *Amaranthus* spp.

The consequence of intensive glyphosate use in GR crops was greater selection pressure on the weed community, resulting in evolution of glyphosate resistance (Heap 2011). Sustainable use of glyphosate can only be maintained by implementing herbicide rotation and diversification of herbicides with differing MOAs (Duke and Powles 2009). Growers acknowledge the likelihood of weed population shifts but have less understanding of the implications of selection pressure on the weed community and evolution of herbicide resistance (Owen 2008). Consequently, evolved resistance to glyphosate has been rapid during the past decade because growers have seldom implemented weed control options other than glyphosate in GR crops. Adoption of reduced tillage systems has also led to an increase in selection pressure and occurrence of evolved resistance because glyphosate is routinely used in many crops to control weeds prior to planting. The trend in herbicide programs for GR crops has been a movement to glyphosate-only systems, notably devoid of residual herbicides. The objective of this survey was to determine herbicide use patterns of growers using GR soybean, cotton, and corn either in continuous production or crop rotation. The reliance of growers using only glyphosate was of particular interest. Results of this survey were designed to complement results from a survey in 2005 prior to the rapid confirmation of evolved resistance to glyphosate.

Materials and Methods

Weed scientists from a diverse geography of universities in Illinois, Iowa, Indiana, Mississippi, Nebraska, and North Carolina developed a Benchmark survey to elicit grower attitudes and awareness regarding glyphosate resistance. This survey was used for a 2005 telephone poll of growers in these states and expanded to include additional states in 2010. States were selected to ensure a mix of cropping practices and environments and to represent major areas of GR crop production. Details of the initial survey are presented elsewhere (Givens et al. 2009a, 2009b, 2011; Johnson et al. 2009; Kruger et al. 2009; Owen et al. 2011; Shaw et al. 2009).

In the winter of 2010, the Benchmark survey from 2005 with a few additional questions (Prince et al. 2012) was re-administered by Market Probe (formerly Marketing Horizons). A random selection of 1,299 growers was made from a list of all growers who signed an agreement with Monsanto Agricultural Products Company (St. Louis, MO) to use GR crops (Roundup Ready™). To qualify for selection, growers were required to (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) have planted GR crops for a minimum of 3 yr. The minimum farm size ensured that survey respondents were full-time growers who derived a significant portion of their livelihood from farming. Producers were disqualified 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 or dealer.

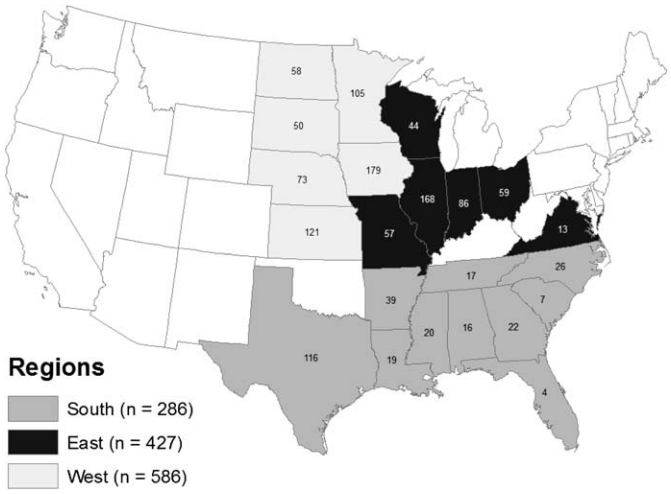


Figure 1. Geographic distribution of regions defined by survey with totals for survey respondants in each state and region.

Growers in the 2010 Benchmark study represented 22 corn and/or soybean states and several states in the cotton region. For some analyses, states were grouped into three geographical regions—South, East, and West (Figure 1). The broad geographic area was thought to represent a national cross section of growers and to better delineate differences that might exist in grower attitudes and perceptions based on crop region.

The first section of the survey focused on crop history, including experience with GR crops. This section was used to divide growers into groups based on cropping systems for subsequent survey sections. The second section of the survey focused on weed population density and tillage practices on a case study field and contained questions about the level of weed populations and weed shifts following adoption of GR cropping systems. The third section, and the section presented in this paper, addressed herbicide use, including application timing and rates. Growers were asked to highlight any changes in herbicide use 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 assigned up to two of nine cropping systems. These cropping systems 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.

Respondents were asked if they had made fall or spring herbicide applications. If the response was positive to one or both of these questions, growers were asked to list all herbicides, including tank mix partners (glyphosate or otherwise) and indicate (for the spring) whether the application was made prior to planting, at planting, or after

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Table 1. Frequency of fall and spring application of herbicides in various cropping systems based on grower surveys conducted in 2005 and 2010.[a,b]

Cropping system	Application during fall		Burndown application during spring	
	2005	2010	2005	2010
	% of growers making each application			
Continuous systems (soybean n_{05} = 307, n_{10} = 152; corn n_{05} = 84, n_{10} = 222; cotton $n_{05,10}$ = 97)				
GR soybean	14	8	60	57
GR corn	13	5	27	26
GR cotton	10	19	76	61
GR corn/GR soybean (n_{05} = 407, n_{10} = 618)				
GR corn	8	7	36	32
GR soybean	6	9	38	36
GR cotton/GR soybean (n_{05} = 38, n_{10} = 33)				
GR cotton	9	16	76	97
GR soybean	9	8	63	82
GR cotton/GR corn (n_{10} = 22)				
GR cotton	—	23	—	77
GR corn	—	23	—	68
GR soybean/non-GR crop (n_{05} = 496, n_{10} = 381)				
GR soybean	8	8	42	42
Non-GR crop	9	6	27	22
GR corn/non-GR crop (n_{05} = 85, n_{10} = 169)				
GR corn	15	14	25	38
Non-GR crop	13	4	20	30
GR cotton/non-GR crop (n_{10} = 70)				
GR cotton	—	26	—	61
Non-GR crop	—	19	—	51

[a] Data for 2005 are from Givens et al. (2009a).

[b] Abbreviation: GR = glyphosate-resistant.

Table 2. Percentage of hectares treated with herbicide in various cropping systems.[a]

Cropping system	Application during fall	Burndown application during spring	Application of nonglyphosate herbicide
Continuous systems			
GR soybean	4	47	25
GR corn	3	22	67
GR cotton	10	53	43
GR corn/GR soybean			
GR corn	6	26	53
GR soybean	4	28	30
GR cotton/GR soybean			
GR cotton	17	97	80
GR soybean	5	81	—
GR corn/GR cotton			
GR corn	38	58	—
GR cotton	27	66	53
GR soybean/non-GR crop			
GR soybean	6	36	N/A[a]
Non-GR crop	8	20	N/A
GR corn/non-GR crop			
GR corn	18	39	N/A
Non-GR crop	14	29	N/A
GR cotton/non-GR crop			
GR cotton	23	60	N/A
Non-GR crop	29	55	N/A

[a] Abbreviations: GR = glyphosate-resistant; N/A= not applicable (question was not asked).

crop emergence. Growers in a crop rotation were asked these questions for each crop in the rotation.

Data for the survey were analyzed using frequency counts and summary statistics to determine totals and percentages for responses. Growers frequently provided multiple answers to questions. These data were pooled before frequency counts were taken. Percentages reported are normalized to 100% in many cases. This was also necessary because growers could provide multiple answers, thus percentages frequently represent a portion of the total number of herbicide applications made in lieu of total growers.

Results and Discussion

Overall there was a low incidence of herbicide use in the fall compared with use in the spring (Table 1). Less than 26% of growers made fall applications prior to planting; for some cropping systems, only 5% of growers made a fall application. When compared with the results of the previous 2005 Benchmark survey (Givens et al. 2009a), major changes were observed in the percentages of growers in continuous GR systems with regard to their use of herbicides in the fall. Fall applications by growers of continuous GR soybean and continuous GR corn decreased considerably, decreasing from 14% in 2005 to 8% in 2010 for soybean growers and from 13% for 2005 to 5% in 2010 for corn growers. The opposite trend was observed for growers in continuous GR cotton, for which the percentage of growers making fall herbicide applications increased from 10 to 19% between 2005 and 2010. Other cropping systems were more static between 2005 and 2010.

Percentages for burndown applications in the spring were consistently higher than percentages of fall applications. Overall, use of burndown herbicides in the spring was observed in the majority of cropping systems. If cropping systems with limited numbers ($n < 50$) are disregarded due to the bias low sample numbers exert on percentages, as many as 76% of growers applied herbicides in the spring prior to planting. Percentages ranged widely, however, and some cropping systems had only 22% of growers applying herbicide at this time (Table 1).

Less than 30% of hectares considered in the survey received a herbicide in the fall (Table 2). Depending on the cropping system, only 4% of hectares received a fall application. Ten percent or less of hectares in continuous GR production received herbicide in the fall. Cropping systems that used crop rotations had somewhat higher percentages of hectares receiving herbicide treatments in the fall. Growers with rotations involving soybean consistently applied few herbicides in the fall. Young (2006) also reported a shift in soybean weed management from diverse herbicide programs with preplant (PP), PRE, and POST herbicides to POST only herbicides in GR soybean. Those rotations involving cotton consistently had higher percentages of hectares being treated

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Table 3. Frequency of application of fall (F) and spring (S) herbicides in various cropping systems.[a]

	EPSP synthase inhibitor		ALS inhibitor		Synthetic auxins		Photosystem I inhibitor		Photosystem II inhibitor		Glutamine synthetase inhibitor		Mitosis inhibitor		PPO inhibitor	
Crop rotation	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S
	% of applied herbicide															
Continuous systems																
GR soybean	3	46	—	—	3	15	—	2	—	—	—	—	—	—	1	5
GR corn	1	15	—	—	1	4	—	1	—	—	—	—	—	—	1	—
GR cotton	10	48	—	—	—	12	—	3	—	—	—	—	—	—	3	7
GR corn/GR soybean																
GR corn	2	14	—	—	3	5	—	—	2	3	—	—	—	—	—	1
GR soybean	2	22	—	—	3	6	—	—	—	1	—	—	—	—	—	2
GR cotton/GR soybean																
GR cotton	3	54	—	—	9	21	—	—	—	—	—	—	—	—	—	12
GR soybean	3	51	—	—	3	15	—	—	—	—	—	—	—	—	—	6
GR cotton/GR corn																
GR cotton	5	37	—	—	5	14	—	—	—	—	—	—	—	—	—	5
GR corn	18	46	—	—	5	9	—	—	—	14	—	—	—	—	—	5
GR soybean/non-GR crop																
GR soybean	3	32	—	2	3	11	—	1	2	1	—	1	—	1	1	4
Non-GR crop	3	14	—	1	3	6	—	2	3	6	—	—	—	1	1	—
GR corn/non-GR crop																
GR corn	10	29	2	1	6	7	—	—	5	5	—	—	—	5	1	—
Non-GR crop	8	24	—	1	2	7	—	1	3	5	—	—	—	2	1	2
GR cotton/non-GR crop																
GR cotton	18	55	—	—	6	11	—	4	—	—	—	—	4	—	1	—
Non-GR crop	15	42	—	—	3	4	—	4	1	3	—	—	3	4	—	4

[a] Abbreviations: GR = glyphosate-resistant; EPSP = enolpyruvyl shikimate-3-phosphate; ALS = acetolactate; PPO = protoporphyrinogen oxidase.

with fall applications. Whether this observation is a function of cotton production, the region where the crop is grown, or a combination of both cannot be determined from this survey data. However, the greater reliance on fall herbicide applications is important to note when evaluating the diversity of herbicides used for weed management in cotton production.

As much as 97% of hectares in some cropping systems were treated in the spring with a PP burndown application. Continuous GR corn and GR corn/GR soybean rotation systems had lower percentages of PP herbicides in the spring than other systems. Compared with results from 2005 (Givens et al. 2009a), a notable decrease was observed in use of burndown herbicides for continuous GR cotton. Marked increases were evident in both crops for GR cotton/GR soybean rotations, and GR corn crops in a rotation with a non-GR crop.

Glyphosate was the most popular choice for fall and spring herbicide applications (Table 3). Dicamba or 2,4-D, both synthetic auxins, were applied during both fall and spring. Protoporphyrinogen oxidase (PPO) inhibitors were also a component for spring applications but were seldom used in fall. Syntheic auxins and PPO inhibitors most likely were used to manage GR weeds (S. Culpepper, personal communication). A wide range of herbicide MOAs other than synthetic auxins, glyphosate, or PPO inhibitors were used in non-GR crops.

In agreement with the 2005 Benchmark survey (Givens et al. 2009a), the majority of growers made two or fewer POST applications of glyphosate after crop and weed emergence (Table 4). Growers of GR cotton more commonly reported applying glyphosate three or more times, except when GR cotton was rotated with GR corn. Less than 5% of growers indicated that glyphosate was not applied in GR crops. Across all systems, GR soybean growers made 1.8 applications, GR corn growers made 1.3 applications, and GR cotton growers made 2.3 applications of glyphosate. The frequency of glyphosate applications in this 2010 survey are markedly higher than U.S. Department of Agriculture data in 2002 (adapted by Young 2006) in which soybean, corn, and cotton received an average of 1.4, 1.1, and 1.8 applications of glyphosate, respectively.

Growers in a rotation with a non-GR crop were not asked on how many hectares they had applied nonglyphosate herbicides. In the remaining cropping systems, for which the question was asked, up to 80% of hectares were treated with a nonglyphosate herbicide. For some cropping systems, however, only 25% of hectares were treated with a nonglyphosate herbicide. Growers in continuous GR corn treated a much higher percentage of hectares with nonglyphosate herbicides than those in other continuous systems. Growers in these systems indicated they were targeting specific weeds and residual control when they chose a nonglyphosate herbicide. In rotations, GR soybean was less likely to receive a

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Table 4. Frequency of glyphosate applications in various cropping systems based on grower surveys conducted in 2005 and 2010.[a,b]

Cropping system	1 application		2 applications		≥3 applications		Did not apply	
	2005	2010	2005	2010	2005	2010	2005	2010
	% of growers making each application							
Continuous systems (soybean n_{05} = 307, n_{10} = 152; corn n_{05} = 84, n_{10} = 222; cotton $n_{05,10}$ = 97)								
GR soybean	23	25	62	55	12	20	2	1
GR corn	54	65	42	31	2	1	1	3
GR cotton	12	15	44	39	42	42	—	3
GR corn/GR soybean (n_{05} = 407, n_{10} = 618)								
GR corn	63	65	32	29	2	2	3	4
GR soybean	48	39	47	55	3	4	2	2
GR cotton/GR soybean (n_{05} = 38, n_{10} = 33)								
GR cotton	18	15	47	55	29	27	—	—
GR soybean	26	15	53	70	13	12	3	3
GR cotton/GR corn (n_{10} = 22)								
GR cotton	—	23	—	64	—	14	—	—
GR corn	—	45	—	45	—	5	—	5
GR soybean/non-GR crop (n_{05} = 496, n_{10} = 381)								
GR soybean	52	35	43	57	4	7	1	1
Non-GR crop	—	—	—	—	—	—	—	—
GR corn/non-GR crop (n_{05} = 85, n_{10} = 169)								
GR corn	61	53	31	38	2	4	6	3
Non-GR crop	—	—	—	—	—	—	—	—
GR cotton/non-GR crop (n_{10} = 70)								
GR cotton	—	14	—	41	—	41	—	1
Non-GR crop	—	—	—	—	—	—	—	—

[a] Data for 2005 are from Givens et al. (2009a).

[b] Abbreviation: GR = glyphosate-resistant.

nonglyphosate herbicide than other rotated crops. Growers in a rotation with GR soybean primarily cited the need to control volunteer corn as their reason for using a nonglyphosate herbicide. Growers with GR corn were most likely to cite residual weed control as their reason for applying a nonglyphosate herbicide.

As with fall-timed herbicide applications, the percentage of growers in continuous GR soybean and GR corn who did not apply a nonglyphosate herbicide decreased compared with the 2005 Benchmark survey (Givens et al. 2009a); the percentage increased for continuous GR cotton growers. In the continuous GR systems, substantial changes within timings were noted between the previous Benchmark survey and the current, particularly with GR cotton PRE and POST applications.

Application timing for nonglyphosate herbicides varied between cropping systems (Table 5). Postemergence was the highest percentage of applications in any system, while PP and PRE timings alternated in importance depending on the specific cropping system. These findings were similar to those of Givens et al. (2009a) in the previous Benchmark survey. There was a strong reliance on POST systems for weed control with nonglyphosate herbicides.

The most commonly chosen herbicide MOA for nonglyphosate herbicides were photosystem II inhibitors (e.g., atrazine), mitotic inhibitors (e.g., pendimethalin, metolachlor), and PPO inhibitors (Table 6). Most of the applications of photosystem II inhibitors included atrazine in corn and diuron or fluometuron in cotton. Atrazine continues to be the dominant broadleaf herbicide in corn, especially with increasing selection for evolved resistance to glyphosate and acetolactate synthase–inhibiting herbicides. Growers indicated that atrazine was applied for residual weed control up to 39% of the time. Mitotic inhibitors were consistently chosen by all cropping systems, except continuous GR soybean, perhaps reflecting the trend observed in a decreased reliance on PRE herbicides in this crop. Growers choosing a mitotic inhibitor cited early and residual control. This was done primarily with acetochlor alone or in a tank mix with atrazine.

Trends in this survey agreed with those of Young (2006), with growers strongly favoring POST weed control systems. Growers continued to rely on glyphosate for the majority of their weed control, although there was some indication that the frequency, while still high, was decreasing, especially in continuous GR soybean and GR corn systems. Development of evolved GR weeds most likely is the contributing factor in increased herbicide diversity. Growers did not increase the annual number of glyphosate applications from 2005 to 2010 but often supplemented glyphosate with herbicides representing other MOAs (Givens et al. 2009a). While increasing the diversity of herbicides is beneficial in preventing or delaying evolved resistance to glyphosate, trends in use of alternatives to glyphosate are selecting for resistance to these herbicide MOA. For example, common waterhemp (*Amaranthus tuberculatus* syn. *rudis*), a weed resistant to five different MOAs (Heap 2011), presents a significant challenge for

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Table 5. Frequency of different herbicide application timings for nonglyphosate herbicides in various cropping systems based on grower surveys conducted in 2005 and 2010.[a,b]

	Prior to planting		At planting		Postemergence		Did not apply	
Cropping system	2005	2010	2005	2010	2005	2010	2005	2010
	% of growers making an application						% of growers	
Continuous systems								
GR soybean	27	34	7	9	67	57	85	67
GR corn	23	19	31	27	46	51	57	33
GR cotton	11	40	11	20	78	40	36	51
GR corn/GR soybean								
GR corn	35	24	39	34	25	41	56	40
GR soybean	53	43	12	11	35	46	84	69
GR cotton/GR soybean								
GR cotton	5	14	8	25	88	60	47	24
GR soybean	24	16	—	32	76	52	79	48
GR soybean/non-GR crop								
GR soybean	52	33	10	10	38	57	81	69
Non-GR crop	18	12	38	24	44	64	23	29
GR corn/non-GR crop								
GR corn	27	15	40	25	32	60	45	43
Non-GR crop	13	21	32	15	55	64	33	40
GR cotton/non-GR crop								
GR cotton	—	27	—	16	—	52	—	46
Non-GR crop	—	24	—	25	—	49	—	30

[a] Data for 2005 are from Givens et al. (2009a).

[b] Abbreviation: GR = glyphosate-resistant.

Table 6. Frequency of nonglyphosate herbicides applied in various cropping systems based on grower surveys conducted in 2005 and 2010.[a]

Crop rotation	Unknown[b]	ALS inhibitor	4-HPPD inhibitor	Photosystem I inhibitor	Photosystem II inhibitor	ACCase inhibitor	Mitosis inhibitor	PPO inhibitor	Glutamine synthetase inhibitor	Synthetic auxins
	% of applied herbicide									
Continuous systems										
GR soybean	—	3	—	—	—		—	6	—	
GR corn	—	—	13	—	5		18	7	—	
GR cotton	4	16	—	3	5		12	—	—	
GR corn/GR soybean										
GR corn		—	5	—	24	—	14	1	—	1
GR soybean		—	—	—	—	5	1	—	—	3
GR cotton/GR soybean										
GR cotton		15	—	—	21	—	6	15	—	9
GR soybean		—	—	—	—	—	15	12	—	3
GR cotton/GR corn										
GR cotton		9	—	—	32	—	27	23	—	—
GR corn		—	—	—	32	—	23	—	—	—
GR soybean/non-GR crop										
GR soybean	3	—	—	—	—	—	4	3	—	1
Non-GR crop	1	—	3	—	15	—	7	—	5	6
GR corn/non-GR crop										
GR corn	1	—	5	—	18	—	9	—	1	2
Non-GR crop	5	4	2	—	7	—	11	1	1	12
GR cotton/non-GR crop										
GR cotton	9	7	—	—	6	—	34	4	—	4
Non-GR crop	9	9	—	—	23	—	18	6	—	9

[a] Abbreviations: ALS = acetolactate; GR = glyphosate-resistant; HPPD = hydroxyphenyl-pyruvate-dioxygenase; ACCase = acetyl CoA carboxylase; PPO = protoporphyrinogen oxidase.

[b] Organoarsenicals.

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growers seeking new options for chemical control. Advisors to cotton and soybean growers are expressing considerable concern over possible selection of biotypes resistant to PPO inhibiting herbicides (S. Culpepper, personal communication).

Use of a residual herbicide with a different MOA than glyphosate is one of the best management practices for managing GR weeds and protecting crop yield from early season weed interference (Loux et al. 2011; Neve et al. 2011). The need for residual weed control appears to be a strong influence when a grower uses a nonglyphosate herbicide for corn growers. Cotton growers were also likely to select herbicides such as pendimethalin and fluometuron that have residual activity. However, this does not appear to be a motivating factor for soybean growers. POST applications were the most commonly reported timing for nonglyphosate herbicides; however, these were not residual herbicides in GR soybean production systems. This seems to indicate continued reliance on POST herbicides and that residual control in POST systems is not always a priority. Collectively, while results from this survey suggest that growers incorporated a greater diversity of herbicides from 2005 to 2010, trends in herbicide use may still encourage excessive selection for evolved resistance to glyphosate. The specific types of herbicides, the frequency of using more than two herbicide MOAs, and the method in which they are being integrated into weed management strategies could be further enhanced to provide a more robust weed control approach. Additional education and promotion efforts across the industry are needed to sustain GR technology.

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