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U.S. Grower Views on Problematic Weeds and Changes in Weed Pressure in Glyphosate-Resistant Corn, Cotton, and Soybean Cropping Systems

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Corn and soybean growers in Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina, as well as cotton growers in Mississippi and North Carolina, were surveyed about their views on changes in problematic weeds and weed pressure in cropping systems based on a glyphosate-resistant (GR) crop. No growers using a GR cropping system for more than 5 yr reported heavy weed pressure. Over all cropping systems investigated (continuous GR soybean, continuous GR cotton, GR corn/GR soybean, GR soybean/non-GR crop, and GR corn/non-GR crop), 0 to 7% of survey respondents reported greater weed pressure after implementing rotations using GR crops, whereas 31 to 57% felt weed pressure was similar and 36 to 70% indicated that weed pressure was less. Pigweed, morningglory, johnsongrass, ragweed, foxtail, and velvetleaf were mentioned as their most problematic weeds, depending on the state and cropping system. Systems using GR crops improved weed management compared with the technologies used before the adoption of GR crops. However, the long-term success of managing problematic weeds in GR cropping systems will require the development of multifaceted integrated weed management programs that include glyphosate as well as other weed management tactics.
Nomenclature: Glyphosate; foxtail, *Setaria* spp.; johnsongrass, *Sorghum halepense* (L.) Pers.; morningglory, *Ipomoea* spp.; pigweed, *Amaranthus* spp.; ragweed, *Ambrosia* spp.; velvetleaf, *Abutilon theophrasti* Medik.; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L; soybean, *Glycine max* (L.) Merr.
Key words: Crop rotation, glyphosate-resistant crops, glyphosate-resistant weeds, survey, weed shifts.

Widespread adoption of glyphosate-resistant (GR) cropping systems has occurred since the introduction of GR soybean (1996), cotton (1997), and corn (1998). In 2005, over 90% of the soybean and cotton hectares planted in the United States were GR cultivars, and GR corn was grown on nearly 50% of the U.S. corn hectares (Sankula 2006). GR crops have resulted in many growers relying solely on glyphosate for their in-crop herbicide program. However, the use of glyphosate alone will result in shifts of predominant weed species that are not effectively controlled by glyphosate (Hilgenfeld et al. 2004; Wilson 2007). The long-term sustainability of GR-based systems will likely require the inclusion of alternative tactics such as tillage, herbicides other than glyphosate, and more complex crop rotation strategies. These alternatives influence population densities and species shifts (Bárberi et al. 1998; Derksen et al. 2002; Liebman and Davis 2000; Shaner 2000). Although GR cropping systems are viewed as highly effective and cost efficient in controlling weeds (Sammons et al. 2007), there are reports of weeds that are not controlled in GR cropping systems (Culpepper 2006; VanGessel 2001). In a 2003 survey of Indiana growers, nearly 30% of the growers responding to the survey stated that giant ragweed (*Ambrosia trifida* L.) was a problematic summer annual weed, whereas over 40% stated that common chickweed (*Stellaria media* (L.) Vill.) was among their three most problematic winter annual weeds (Gibson et al. 2005). In addition, they showed that tillage system and crop rotation influenced which weed species were problematic within a field. For example, they found that 30% or more of growers with corn in their crop rotation found giant ragweed problematic, whereas that was the case with less than 10% of growers using a continuous soybean cropping system.

Utilization of GR crops has resulted in increased grower reliance on POST weed control with glyphosate. Seven weed species have been reported to demonstrate resistance to glyphosate in the United States (Heap 2007). In addition, selection pressure resulting from annual glyphosate use has resulted in a shift in the dominant weed species in a field toward species such as velvetleaf (Shaner 2000), morningglory (Culpepper et al. 2001), common waterhemp (*Amaranthus rudis* Sauer) (Shaner 2000), nightshade (*Solanum* spp.) (Shaner 2000), and field bindweed (*Convolvulus arvensis* L.) (DeGennaro and Weller 1984).

Surveys in Indiana and Western Australia characterized problem weed species that are difficult to manage, and growers' perceptions of herbicide resistance issues (Barnes et al. 2004; Gibson et al. 2005; Johnson et al. 2004; Llewellyn et al. 2002). Growers in GR-based systems still have problem weeds and a moderate to high level of concern about whether herbicide resistance in weed populations will evolve. The rapid adoption of GR cropping systems by growers suggests that they appreciate and understand the advantages of the technology. However, it is important to understand how growers perceive the overall advantages of using the GR-based system and how their management practices affect weed control and species composition.

A comprehensive phone survey of U.S. growers in six midwestern and southern states was conducted in 2005–2006 to gain insight into their perceptions of GR cropping systems,

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Table 1. Grower perception of weed pressure after implementing glyphosate-resistant (GR) crops into various rotational and tillage systems.

		Perceived change in weed pressure[a]					
				Reduced			
Crop rotation	Tillage	Increased	Same	By tillage system	Averaged over tillage system	*n*	P[b]
		%					
Continuous GR soybean	No till	3	39	58	56	164	0.0010
	Reduced till	5	37	58		81	0.1822
	Conventional till	5	42	53		60	0.2449
Continuous GR cotton	No till	0	49	51	55	37	0.0149
	Reduced till	3	31	66		35	0.7958
	Conventional till	0	52	48		25	0.0392
GR corn/GR soybean	No till	3	31	66	66	175	0.0749
	Reduced till	2	36	62		160	0.0008
	Conventional till	3	27	70		63	0.0409
GR soybean/non-GR crop	No till	1	42	57	54	162	< 0.0001
	Reduced till	1	43	56		240	< 0.0001
	Conventional till	2	48	50		89	< 0.0001
GR corn/non-GR crop	No till	6	49	45	44	31	0.1928
	Reduced till	5	43	52		40	0.2302
	Conventional till	7	57	36		14	0.1396

[a] Increased = greater weed pressure after introducing GR crops; same = no change in weed pressure after introducing GR crops; reduced = less weed pressure after introducing GR crops.

[b] P-values were calculated using chi-square analysis in SAS 9.1.

weed abundance, management before and after GR crops, and their understanding of selection pressure and its effects on weed populations within these fields (for background information on the survey, see Shaw et al., unpublished data). Information from this survey will be a useful guide in developing weed management strategies to ensure the sustainability of GR cropping systems while reducing weed populations and avoiding the selection, buildup, and dispersal of GR weed species.

Materials and Methods

Nearly 1,200 growers from six states (Iowa, Illinois, Indiana, Mississippi, North Carolina, Nebraska) were surveyed by phone over a 2-month period in late 2005 and early 2006. Complete details of survey respondent selection criteria, survey methods, and survey questions are described in Shaw et al. (unpublished data). These states were selected to represent the major GR crop-growing regions of the United States, and for their diversity of environments, cropping systems, and weed populations. A list of all growers from these states who had signed an agreement to use the GR crop [Roundup Ready™] technology was obtained from Monsanto[1] for the states to be surveyed, and survey respondents were randomly selected from this list. Respondents were initially asked whether they were actively involved in farming, if they were responsible for the decisions concerning the seeds, traits, and herbicides purchased for their operation, if they planted a minimum of 101 ha of corn, soybean, or cotton in 2005, and if they planted one of the traits or trait combinations for a minimum of 3 yr. Producers were disqualified from the survey if they or 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 results presented in this paper focus on problem weeds and weed shifts. Growers were asked their awareness level of the potential of GR weeds to develop, how serious they considered this issue to be, if they were aware of any GR weeds in their state, and what weed shifts had occurred. Chi-square analysis of data using PROC FREQ (SAS 9.1) was used to determine the relative significance of responses. Before analysis, grower responses were grouped into one of five cropping systems: (1) continuous GR soybean ($n = 268$), (2) continuous GR cotton ($n = 82$), (3) GR corn rotated with GR soybean ($n = 354$), (4) GR soybean in rotation with a non-GR crop ($n = 360$), and (5) GR corn in rotation with a non-GR crop ($n = 64$). Growers were asked to rate weed pressure in their farming operations on a scale from 1 to 10 with 1 meaning light weed pressure or low relative abundance and 10 indicating heavy weed pressure or high abundance. For purposes of analysis, individual responses were grouped with ratings of 1 to 3 indicative of light weed pressure, 4 to 7 moderate, and 8 to 10 heavy weed pressure. To assess the influence of tillage on grower responses, further analysis was based on whether growers used no-tillage, reduced-tillage, or conventional-tillage practices in their specific GR-based system.

Results and Discussion

Changes in Weed Pressure. After implementing a cropping system that utilized a GR crop, 36 to 70% of the respondents felt that weed pressure decreased, 0 to 7% felt that weed pressure increased, and 31 to 57% felt that weed pressure remained unchanged (Table 1). Within the various cropping and tillage systems there were some interesting responses concerning weed pressure. Growers using a GR corn/non-GR

Table 2. Comparison of the number of years that a field has been in a glyphosate-resistant (GR) cropping system to grower perception of the weed pressure in the field.

	Cropping system/weed pressure														
	Continuous GR soybean			Continuous GR cotton			GR corn/GR soybean			GR soybean/non-GR crop			GR corn/non-GR crop		
Years	Heavy	Moderate	Light	Heavy	Moderate	Light	Heavy	Moderate	Light	Heavy	Moderate	Light	Heavy	Moderate	Light
	%														
2	0	2	2	0	2	2	1	4	4	1	2	3	2	8	8
3	2	12	28	1	12	16	2	12	32	1	8	14	3	12	25
4	2	7	14	1	8	16	2	5	12	1	9	10	5	11	11
5	1	6	9	1	15	11	1	3	11	1	7	17	0	8	2
6	0	4	5	0	6	2	0	2	6	0	8	8	0	2	3
7	0	2	4	0	0	7	0	1	2	0	4	6	0	0	0
Column total	5	33	62	3	43	54	6	27	67	4	38	58	10	41	49
P[a]		0.8868			0.6050			0.1816			0.1665			0.3848	
n		268			82			354			360			64	

[a] P-values were calculated using chi-square analysis in SAS 9.1.

crop rotation were the most likely to mention an increase in weed pressure (5 to 7%) and were the least likely to mention a decrease in the weed pressure (36 to 52%). This may be related to the probability that these growers were in a GR crop rotation for fewer years than those in a GR soybean or GR cotton crop rotation and had not yet achieved a similar decrease in weed pressure. With the variety of herbicide products available in corn, a major change in herbicide program can require a period of adjustment to learn how to best use GR programs, alone or integrated with other herbicides. Nevertheless, even in the conventional-tillage GR corn/non-GR crop rotation, over one-third of the respondents felt that weed pressure decreased, whereas only 7% felt that it increased. Growers rotating GR corn/GR soybean were most likely to observe a decrease in weed pressure (62 to 70%) and, unlike all other cropping systems, the conventional-tillage system was perceived to provide greater benefits in reducing weed pressure than either reduced- or a no-tillage system. Thus, substantial variation occurs between cropping and tillage systems regarding the perception of changes in weed pressure with introduction of GR technology. We feel that growers are underestimating the impact and benefits of tillage on weed pressure.

The length of time in a particular GR cropping system (2 to 7 yr) did not affect grower perceptions of weed pressure (light, moderate, heavy); however, most growers considered their weed pressure to be moderate or light (Table 2). In all

Table 3. Grower perceptions of the most problematic weeds in various glyphosate-resistant (GR) crop rotation systems.

	Continuous GR soybean		Continuous GR cotton		GR corn/GR soybean		GR soybean/non-GR crop		GR corn/non-GR crop	
Weed	Before	After	Before	After	Before	After	Before	After	Before	After
	% of respondents within a rotation[a]									
Grass (general)	7	13	16	6	9	6	8	7	8	7
Johnsongrass[b]	22	9	14	9	10	6	10	5	-	-
Foxtail	15	9	-	-	35	20	34	25	35	20
Crabgrass	-	-	8	4	-	-	-	-	-	-
Shattercane[b]	-	-	-	-	6	3	6	3	-	-
Woolly cupgrass[b]	-	-	-	-	6	3	-	-	7	4
Morningglory	26	24	54	47	5	4	8	8	-	-
Ragweed	15	10	-	-	19	13	21	15	11	11
Common cocklebur[b]	26	9	28	7	22	10	20	9	11	8
Pigweed species	12	9	26	25	8	4	5	4	15	8
Common waterhemp	9	8	-	-	20	20	15	15	17	13
Velvetleaf	7	6	-	-	24	16	27	18	18	13
Arrowleaf sida	6	6	-	-	-	-	-	-	-	-
Sicklepod[b]	10	5	16	9	-	-	6	2	-	-
Sunflower[b]	-	-	-	-	13	8	9	6	17	9
Lambsquarters	-	-	-	-	9	5	11	7	14	11
Canada thistle[b]	-	-	-	-	-	-	-	-	6	9
Kochia[b]	-	-	-	-	-	-	-	-	8	5
Don't know	2	10	0	6	1	11	3	7	1	11
n	307		97		407		496		85	

[a] "-" indicates that both before and after responses were less than 5%.

[b] Scientific names of plants not mentioned in text: shattercane [*Sorghum bicolor* (L.) Moench spp. SORVU], wooly cupgrass [*Eriochloa villosa* (Thunb.) Kunth ERBVI], common cocklebur (*Xanthium strumarium* L. XANST), common sunflower (*Helianthus annuus* L. HELAN), Canada thistle [*Cirsium arvense* (L.) Scop. CIRAR], kochia [*Kochia scoparia* (L.) Schrad. KCHSC].

Table 4. Three most commonly mentioned problematic weeds in each state and cropping system.

Cropping system	State[a]					
	Iowa	Illinois	Indiana	Mississippi	North Carolina	Nebraska
Continuous GR[b] soybean	Common waterhemp	Common waterhemp	Ragweed	Morningglory	Morningglory	Velvetleaf
	Velvetleaf	Ragweed	Johnsongrass	Arrowleaf sida	Sicklepod	Shattercane
	Ragweed	Johnsongrass	Horseweed	Sicklepod	Pigweed species	Grass (general)
Continuous GR cotton	NA	NA	NA	Morningglory	Morningglory	NA
	NA	NA	NA	Horseweed	Pigweed species	NA
	NA	NA	NA	Pigweed	Sicklepod	NA
GR corn/ GR soybean	Common waterhemp	Common waterhemp	Ragweed	Morningglory	Morningglory	Common waterhemp
	Foxtail	Ragweed	Bur cucumber	Sicklepod	Pigweed species	Velvetleaf
	Wooly cupgrass	Common cocklebur	Common waterhemp	Velvetleaf	Sicklepod	Foxtail
GR soybean/ non-GR crop	Common waterhemp	Ragweed	Ragweed	Johnsongrass	Morningglory	Common waterhemp
	Foxtail	Common waterhemp	Foxtail	Morningglory	Sicklepod	Velvetleaf
	Velvetleaf	Foxtail	Dandelion	Sicklepod	Signalgrass	Sunflower
GR corn/ non-GR crop	Common waterhemp	Common waterhemp	Johnsongrass	NA	Johnsongrass	Foxtail
	Velvetleaf	Ragweed	Horseweed	NA	Bermuda grass	Sunflower
	Pigweed species	Morningglory	-	NA	-	Johnsongrass

[a] "-" indicates that there were no other responses for that category.

[b] Abbreviations: GR, glyphosate resistant; NA, no survey respondents from this state in this rotation.

systems, 49 to 66% of growers felt that weed pressure was light, whereas 27 to 43% felt that weed pressure was moderate. Most respondents surveyed had been using a GR cropping system for 3 to 5 yr and no more than 5% of them believed they had heavy weed pressure, regardless of the specific GR crop. No grower in any crop rotation system felt that weed pressure was heavy if they had grown GR crops for more than 5 yr.

Problematic Weeds before and after Adoption of GR Crops. Growers' responses about their most problematic weeds varied greatly with the type of GR cropping system (Table 3). Weeds such as morningglory, ragweed, pigweed, and common waterhemp were assessed to be problematic in more than one GR cropping system. Grass pressure was reported to remain the same in the GR cropping systems that included rotation to a non-GR crop. Also, continuous GR soybean systems resulted in little to no perceived improvement for control of common waterhemp, velvetleaf, and arrowleaf sida (*Sida rhombifolia* L.).

A survey of weed scientists employed by universities indicated that management decisions in GR cropping systems were causing weed shifts, and that the weed shifts were increasing the costs of weed management (Culpepper 2006). The data from this survey suggest that most species, except for morningglories and pigweeds, present before GR crop introduction continue to be problematic, but to a reduced degree after implementing a GR cropping system. Interestingly, the survey reported by Culpepper (2006) indicated that 67 and 50% of weed scientists surveyed consider morningglory and pigweed, respectively, to be more problematic after GR cotton adoption. This observation is supported by our data regarding grower perceptions of problematic weeds and is likely due to reduced use of many soil-applied and postdirected herbicides that effectively control these weeds.

Another interesting aspect of our survey was that 6 to 11% of respondents did not know what their most problematic weeds were after implementing a GR cropping system. This may be a reflection of their confidence in the effectiveness of glyphosate for controlling weeds or an indication of their ability to identify a problematic weed. There are several possible explanations for these observations. The first is that after implementing a GR-based cropping system, there are no longer any weeds that are considered problematic. Another possible explanation could be that the efficacy of glyphosate in a GR cropping system has caused some growers to pay less attention to which weeds are causing problems in their fields. If this is the case, it is a dangerous omen for the adoption of integrated weed management techniques.

Problematic Weeds Now and Beyond. The most commonly mentioned problematic weeds across all GR cropping systems and all states were ragweed, johnsongrass, velvetleaf, morning-

Table 5. Percentage of survey respondents who stated that they have no major weed problems.

Cropping system	State						
	Iowa	Illinois	Indiana	Mississippi	North Carolina	Nebraska	Mean
	% of respondents						
Continuous GR[a] soybean	27	39	27	24	25	8	25
Continuous GR cotton	NA	NA	NA	33	28	NA	31
GR corn/GR soybean	31	30	36	28	25	29	30
GR soybean/non-GR crop	42	21	33	24	24	24	28
GR corn/non-GR crop	55	33	0	NA	67	38	39

[a] Abbreviations: GR, glyphosate resistant; NA, no survey respondents from this state in this rotation.

glory, sicklepod (*Senna obtusifolia* (L.) H. S. Irwin & Barneby), and pigweed (Table 4). In Iowa and Illinois, common waterhemp was mentioned most frequently. In Indiana, ragweed was mentioned most frequently, which is similar to that reported in a grower survey conducted in 2003 (Gibson et al. 2005, 2006; Johnson et al. 2004), whereas in Nebraska, velvetleaf and common waterhemp were most common. In Mississippi and North Carolina, morningglory, sicklepod, and pigweed were most commonly mentioned. Morningglory (Culpepper et al. 2001), sicklepod (Clay and Griffin 2000), and velvetleaf (Gonzini et al. 1999) are known to be difficult to control with glyphosate. A few of the weeds mentioned in this survey, including common waterhemp, ragweed, and horseweed (*Conyza canadensis* (L.) Cronq.), have already evolved resistance to glyphosate (Heap 2007). A question raised from this survey is whether or not weeds such as velvetleaf, arrowleaf sida, or a specific grasses species such as giant foxtail (*Setaria faberi* Herrm.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), or crabgrass (*Digitaria* spp.) have the potential to evolve resistance to glyphosate, or if they have simply adapted to capitalize on an ecological niche in GR-based cropping systems as suggested by Cardina et al. (2002).

It is of note that a substantial percentage of grower respondents did not report major weed problems (Table 5). In systems utilizing only GR crops, 25 to 31% of the responding growers indicated that they have no major weed problems, whereas 28 to 39% of those rotating to a non-GR crop mentioned no major weed problems. These findings suggest some benefit to rotating to a non-GR crop and subsequent use of herbicides other than glyphosate for summer annual and perennial weed control. GR cropping systems have been widely adopted and have achieved satisfactory weed control in the opinion of most growers who participated in the current survey. Glyphosate use in GR-based systems has provided growers with an effective tool for preplant and POST weed control. Glyphosate use in GR cropping systems, with proper stewardship and attention to changes in weed populations, will likely continue to be an effective tool for managing weeds for the foreseeable future. However, appropriate adjustments will need to be made to these systems, including using other herbicides in combination with glyphosate or tillage to manage both GR weeds and other difficult-to-control weeds.

Sources of Materials

[1] Monsanto Agricultural Products Company, 800 North Lindbergh Boulevard, St. Louis, MO 63167.

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