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U.S. Farmer Awareness of Glyphosate-Resistant Weeds and Resistance Management Strategies

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A survey of farmers from six U.S. states (Indiana, Illinois, Iowa, Nebraska, Mississippi, and North Carolina) was conducted to assess the farmers' views on glyphosate-resistant (GR) weeds and tactics used to prevent or manage GR weed populations in genetically engineered (GE) GR crops. Only 30% of farmers thought GR weeds were a serious issue. Few farmers thought field tillage and/or using a non-GR crop in rotation with GR crops would be an effective strategy. Most farmers did not recognize the role that the recurrent use of an herbicide plays in evolution of resistance. A substantial number of farmers underestimated the potential for GR weed populations to evolve in an agroecosystem dominated by glyphosate as the weed control tactic. These results indicate there are major challenges that the agriculture and weed science communities must face to implement long-term sustainable GE GR-based cropping systems within the agroecosystem.
Nomenclature: Glyphosate.
Key words: Genetically engineered crops, glyphosate-resistant crops, herbicide resistance, perceptions, surveys.

Genetically engineered (GE) glyphosate-resistant (GR) crops were first commercially introduced in 1996, and have been the most rapidly accepted new agronomic crop trait in the history of agriculture. Although data vary on the area of GE crops, there were a reported 114.3 million ha of GE crops grown in 23 countries by more than 12 million farmers in 2007 (James 2008). Since 1996, more than a billion cumulative acres (400 million ha) of GE crops have been planted in the U.S. (Marvier et al. 2008; Sankula 2007). For 2007, the National Agriculture Statistics Service of the U.S. Department of Agriculture (USDA) reported that 70% of upland cotton (*Gossypium hirsutum* L.), 52% of corn (*Zea mays* L.), and 91% of soybean [*Glycine max* (L.) Merr.] hectares were planted with GE GR cultivars (USDA 2007), whereas the Biotechnology Industry Organization (BIO) reported higher percentages for corn (71%) and cotton (87%; Carstoiu 2008).

U.S. farmers account for approximately 50% of the worldwide hectares of GE GR crops grown (James 2008). Rapid adoption of GE GR crops occurred because glyphosate is highly effective against almost all economically important weeds, and its use facilitated widespread adoption of no-tillage (no-till) systems that conserve both soil and energy resources. No-till systems in the United States have increased from 15 million ha to over 25 million ha from 1994 to 2004 (Conservation Technology Information Center [CTIC] 2007). No-till crop systems represent an important environmental and economic benefit to reducing soil erosion and fossil fuel consumption.

Because glyphosate resistance has become the most widely used trait in corn, soybean, and cotton production and has been the most rapidly adopted new crop technology ever, it is important to understand farmer attitudes and perceptions about GR weeds. This information must then be coupled with our science-based knowledge to help guide farmer educational programming aimed at increasing awareness and knowledge of weed resistance to herbicides and hopefully modify farmer behavior toward weed and resistance management.

The specific objectives of this survey were to assess the level of concern among farmers about GR weeds and their perceptions of tactics they believe would help to manage or delay the evolution of GR weeds.

Materials and Methods

A telephone survey was designed to determine farmer opinions of whether GR weeds were a problem in GE GR cropping systems and appropriate tactics for resistance management or prevention. The survey was conducted between November 9, 2005 and January 6, 2006. Approximately 1,200 farmers (200 from each state) from Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina were randomly contacted. These states were selected as they represent major GE GR crop-growing regions of the United States, and for their diversity of environments and cropping systems. Respondents were actively involved in farming; responsible for decisions concerning seeds, traits, and herbicides purchased; had planted at least 101 ha of corn, soybean, or cotton in 2005; and planted GE GR crops for a minimum of 3 yr. A detailed description of the methods used in this survey can be found in Shaw et al. (2009). Chi-square analysis was used to determine if farm

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Table 1. The impact of farm size on awareness of glyphosate resistance in weeds.

	Response	Farm size[a]			P[b]
		Large	Medium	Small	
		% of respondents			
Perception of issues related to resistance					
Aware of weeds' potential to develop resistance	Yes	88	88	75	< 0.0001
Aware of resistance in the state	Yes	40	41	29	0.0035
Perceived seriousness of resistance	High[c]	30	27	21	0.0082
Personally experienced glyphosate resistance	Yes	13	13	19	0.0762
Action taken to prevent glyphosate resistance	Yes	65	63	43	< 0.0001
Opinion of management practices that reduce or prevent resistance					
Following the label	High[c]	78	76	71	0.0021
Rotating crops	High[c]	52	57	52	0.0172
Rotating herbicides	High[c]	55	50	44	0.0087
Tank mixing with a residual herbicide	High[c]	47	45	40	0.0635
Tank mixing with another mode of action	High[c]	45	40	43	0.2478
Using a non-Roundup Ready crop	High[c]	48	49	41	0.0632
Tillage	High[c]	28	27	28	0.6442
Useable responses (N)		490	456	249	

[a] Large farms were > 404 ha, medium farms were between 202 and 404 ha, and small farms were < 202 ha.

[b] P values were calculated with the use of chi-square analysis in SAS 9.1 (Statistical Analysis Systems Institute, Cary, NC).

[c] Respondents were asked to answer on a 1–10 scale. Respondents were then grouped as 1–3 = Low, 4–7 = Moderate, and 8–10 = High.

size, current tillage practices, or state were significant factors in responses.

Results and Discussion

Impact of Farm Size and Tillage Practice on Farmers' Perspectives. Eighty-eight percent of the farmers with > 200 ha were aware of the potential of selecting for GR weed biotypes compared to 75% of those with < 200 ha (Table 1). Fewer < 200-ha farmers (29%) were aware of GR weed populations in their state compared to farmers with > 200 ha (41%). This result is of interest because GR weed populations have been reported in all the states surveyed. Thirty percent or fewer of all farmers thought glyphosate resistance in weeds was a serious agronomic issue. This perspective was likely attributable to the fact that only 13 to 19% had personally experienced GR weeds on their farms.

When asked if preventative tactics against GR weed evolution were used on their farms, the < 200-ha farmers were less likely to implement prevention practices than > 200-ha farmers, even though a higher percentage of the former vs. latter had personally experienced GR weeds (although not significant, 19 vs. 13%). This response may be because more < 200-ha farmers are part-time farmers, generally grow only GE GR crops, and more often rely solely on glyphosate for weed control. Regardless of farm size, less than 50% of farmers thought tank-mixing glyphosate with alternative herbicides or using a non-GR crop in their crop rotations were high priorities for GR weed management. Approximately 28% felt tillage was effective for minimizing glyphosate resistance evolution. A majority of farmers (71 to 78%) reported that following the glyphosate herbicide label for the proper use rate was important in preventing evolution of glyphosate resistance in weeds. Sammons et al. (2007) suggest that using the labeled glyphosate rate to control the most difficult weed in a field would prevent glyphosate resistance evolution in weeds, with which many farmers apparently agree. There is no consensus among university scientists about the utility of this tactic (Owen 2008).

There were no major differences in awareness or concern about GR weeds when farmers used different tillage systems than the responses based on farm size (Table 2). Awareness for potential evolution of glyphosate resistance ranged from 89 to 94% of the farmers. However, similar farmer responses over all tillage systems occurred for awareness of resistance existing in the state, perceived seriousness of GR weeds, personal experience, and actions taken to prevent resistance. These responses reflected those observed for farm size. Conventional-tillage farmers were more likely to use a non-GR crop than no-till farmers. This pattern of responses could be related to conventional-tillage farmers being less dependent on glyphosate prior to crop planting, and because using a non-GR crop in the rotation avoids repeated use of glyphosate, which lowers selection pressure for glyphosate-resistance evolution in weeds. Detailed aspects of farmers' tillage practices based on this survey are discussed in Givens et al. (2009).

Sources of Information on Herbicide Resistance. Farmers were asked an open-ended question about their primary source of information on glyphosate resistance. Two factors influenced where farmers get information on glyphosate resistance—the state in which they reside and their perception of the seriousness of GR weeds (Table 3). Farm press publications were the primary source of information on glyphosate resistance for farmers (54 to 65%; Table 3), and agriculture chemical dealers/retailers (15 to 23%) and universities/cooperative extension services (CES; 10 to 24%) were second. Other sources were mentioned by less than 10% of the respondents. In northern states, farmers more often accessed information from dealers/retailers than southern state farmers. North Carolina farmers were more likely to obtain information from universities/CES than those in other states.

Table 2. Effect of farmer tillage system use on the perceptions of glyphosate resistance issues.

	Response	Tillage system			P[a]
		No-till	Reduced	Conventional	
		% of respondents			
Perception of issues related to resistance					
Aware of weeds' potential to develop resistance	Yes	91	94	89	0.0251
Aware of resistance in the state	Yes	44	43	34	0.0725
Perceived seriousness of resistance	High[b]	29	29	28	0.9945
Personally experienced glyphosate resistance	Yes	17	13	18	0.1255
Action taken to prevent resistance	Yes	61	68	62	0.0543
Opinion of management practices that reduce or prevent resistance					
Following the label	High[b]	74	77	75	0.0086
Rotating crops	High[b]	51	57	55	0.0144
Rotating herbicides	High[b]	46	56	52	0.0043
Tank mixing with a residual herbicide	High[b]	44	46	46	0.0310
Tank mixing with another mode of action	High[b]	43	45	42	0.0254
Using a non-Roundup Ready crop	High[b]	46	42	53	<0.0001
Tillage	High[b]	17	32	38	<0.0001
Useable responses (N)		203	444	457	

[a] P values were calculated with the use of chi-square analysis in SAS 9.1 (Statistical Analysis Systems Institute, Cary, NC).

[b] Respondents were asked to answer on a 1–10 scale. Respondents were then grouped as 1–3 = Low, 4–7 = Moderate, and 8–10 = High.

The Internet was mentioned by less than 1% of the respondents, although much of the information from farm press publication writers and dealers/retailers is obtained from the Internet and originates from university research and extension and agriculture chemical manufacturers.

Farmers with moderate or high levels of concern regarding GR weed management and prevention most often obtained information from universities/CES compared to those with low levels of concern. Farmers with low or moderate levels of concern received their information from dealers/retailers rather than from universities/CES.

This survey represents one of the few robust and wide-scale assessments of the implications of farmer knowledge and attitudes on weed management in GE GR crops in U.S. agriculture. Survey results presented here suggest three alarming observations of farmer attitudes toward practices they might use to stop or slow the evolution of GR weeds. First, farmers with > 200 ha were more concerned about GR than those with < 200 ha. However, only 30% or less of all farmers thought GR weeds were, or could become, a serious problem. This observation is disturbing because there are now many instances of evolved GR weed populations in the United States and the world. The first GR weed in row crops identified in the United States was horseweed [*Conyza canadensis* (L.) Cronq.] reported in Delaware in 2000, and its appearance was correlated with the cultivation of GE GR soybean (VanGessel 2001). Recently, other GR weed populations have been reported, including common ragweed (*Ambrosia artemisiifolia* L.) in Missouri; Palmer amaranth (*Amaranthus palmeri* S.Wats.) in Georgia, Tennessee, and North Carolina; tall waterhemp [*Amaranthus tuberculatus* (Moq.) J.D.Sauer] in Minnesota, Missouri, Iowa, Illinois, and Kansas; and giant ragweed (*Ambrosia trifida* L.) in Minnesota, Indiana, and Ohio (Heap 2009). Frequent glyphosate failures in common lambsquarters (*Chenopodium album* L.) control (Gibson et al. 2005; Johnson et al. 2004) have been reported. All these weeds are major economic problems in agronomic crops in the cornbelt and cotton regions of the United States.

Table 3. Source of farmer information on glyphosate resistance and perception of resistance.

	State[a]						Perception of the seriousness of resistance[b]		
Source of information	IA	IL	IN	MS	NC	NE	High	Moderate	Low
	% of respondents						% of respondents		
Dealers / retailers	18	21	23	15	15	20	16	21	19
Farm publications	61	54	57	65	54	61	61	55	61
Monsanto	0	3	3	0	2	3	2	1	3
Other farmers	4	6	5	8	5	6	6	4	7
Syngenta	1	1	1	0	0	0	0	1	0
University/extension	16	15	11	12	24	10	15	18	10
N	135	145	155	129	143	143	263	311	276
P[c]	0.1180						0.0816		

[a] IA, Iowa; IL, Illinois; IN, Indiana; MS, Mississippi; NC, North Carolina; NE, Nebraska.

[b] Respondents were asked to answer on a 1–10 scale. Respondents were then grouped as 1–3 = Low, 4–7 = Moderate, and 8–10 = High.

[c] P values were calculated with the use of chi-square analysis in SAS 9.1 (Statistical Analysis Systems Institute, Cary, NC).

GR horseweed now has widespread distribution throughout the United States. It is usually accepted that the recurrent use of glyphosate will increase selection pressure for the evolution of additional GR weed biotypes. Thus, glyphosate effectiveness in GE GR crop systems is at serious risk unless programs are developed to educate farmers effectively to choose weed management tactics that prevent or delay glyphosate resistance evolution.

A second alarming observation is that a majority of survey respondents thought that following the glyphosate label rate recommendation was the most effective strategy for reducing or preventing GR weeds; very few thought that tillage and not using a GE GR crop would be effective strategies. To date, there are four other peer-reviewed reports of farmer perceptions about the impact of GR weeds (Christoffoleti et al. 2008; Foresman and Glasgow 2008; Johnson and Gibson 2006; Llewellyn et al. 2002). Llewellyn et al. (2002) surveyed farmers in Western Australia regarding herbicide resistance in rigid ryegrass (*Lolium rigidum* Gaudin). They concluded that farmers believed new herbicides would be introduced in time to control herbicide-resistant weeds and generally chose not to adopt alternative weed management tactics. The attitudes among U.S. farmers are similar, according to Johnson and Gibson (2006). The problem with this attitude is that no new herbicides with novel mechanisms of action are in the latter stages of development, and no herbicides with new modes of action have been released since 1990. Because development time of a new pesticide is at least 11 yr and the cost is greater than $190 million, it is unlikely that herbicides with new modes of action will become available to farmers in the next 5 yr or longer (Fernandez-Cornejo et al. 1998). In addition, USDA Agriculture Census data (USDA 2003) indicate that over 80% of the total number of farms have 199 ha or less, suggesting that there is a large number of part-time farmers. These farmers were less aware of glyphosate resistance in weeds than were the larger-hectarage, full-time farmers (Table 1). Thus, a substantial percentage of farmers will continue to underestimate the potential for GR weed populations to evolve in a landscape dominated by frequent and repeated use of glyphosate. These data indicate that the first step in a proactive program is to add to herbicide labels information that educates farmers on techniques of herbicide use and stewardship practices that will avoid or reduce the incidence of evolved GR weeds.

The third alarming observation is that printed farm press publications appear to be the most important source of information to farmers concerning herbicide resistance. Information in farm press and retailer publications originates largely from land-grant university–based research results. This information is often supplemented with results from life sciences companies. However, the presentation of this information is not consistent, which leads to some confusion on the farmer's part as to what exactly is the most appropriate integrated weed management approach(es) to use in GE GR crops. This situation suggests that all organizations (farmer groups, universities, life sciences companies, government) must work together to provide a consistent message describing the best recommendations on herbicide resistance management and other priorities that minimize the impact of GE crops on the agroecosystem. Farmers will then have the educational base and confidence to choose appropriate approaches to integrated weed management in GE GR crops.

The weed science community must consider important research areas when developing glyphosate resistance management strategies. For example, we actually know little about the biochemical mechanisms for glyphosate resistance in weeds; research into specific mechanisms could help in developing more sustainable management practices. Programs need to develop and transfer technology to farmers for economically sustainable and environmentally acceptable chemical management of weeds. To address this larger issue, a multistate field-scale project is underway in the six U.S. states where this survey was conducted. The objective is to compare GE GR–based crop production system practices with alternative input approaches to determine whether current GE crop production systems are sustainable (Shaw et al. 2007). The project will encompass field-scale assessments of weed management tactics in a variety of crop rotation systems over a number of years. Data from this project will provide an excellent base upon which the risks and benefits of GE crops can be assessed, not only from an economic standpoint, but also from an ecological impact perspective.

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