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Education/Extension

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

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Over 175 growers in each of six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina) were surveyed by telephone to assess their perceptions of the benefits of utilizing the glyphosate-resistant (GR) crop trait in corn, cotton, and soybean. The survey was also used to determine the weed management challenges growers were facing after using this trait for a minimum of 4 yr. This survey allowed the development of baseline information on how weed management and crop production practices have changed since the introduction of the trait. It provided useful information on common weed management issues that should be addressed through applied research and extension efforts. The survey also allowed an assessment of the perceived levels of concern among growers about glyphosate resistance in weeds and whether they believed they had experienced glyphosate resistance on their farms. Across the six states surveyed, producers reported 38, 97, and 96% of their corn, cotton, and soybean hectarage planted in a GR cultivar. The most widely adopted GR cropping system was a GR soybean/non-GR crop rotation system; second most common was a GR soybean/GR corn crop rotation system. The non-GR crop component varied widely, with the most common crops being non-GR corn or rice. A large range in farm size for the respondents was observed, with North Carolina having the smallest farms in all three crops. A large majority of corn and soybean growers reported using some type of crop rotation system, whereas very few cotton growers rotated out of cotton. Overall, rotations were much more common in Midwestern states than in Southern states. This is important information as weed scientists assist growers in developing and using best management practices to minimize the development of glyphosate resistance.

Nomenclature: Glyphosate; corn, *Zea mays* L.; cotton, *Gossipium hirsutum* L.; rice, *Oryza sativa* L.; soybean, *Glycine max* (L.) Merr.

Key words: Crop diversity, crop rotation, glyphosate-resistant crops, resistance management, survey.

The choice of components in a cropping system has a substantial impact on weed management. Diversified cropping systems that capitalize on benefits from varying seeding date, crop life cycle, herbicide sites of action, herbicide timing, crop residue layer, and soil disturbance may effectively and economically manage weed populations, and reduce the weed seedbank (Ball 1992; Bárberi and Lo Cascio 2001; Derksen et al. 2002; Hutcheon et al. 1998; Kegode et al. 1999; Unger et al. 1999). Conversely, remaining in the same cropping system over a long period results in selection of weed species that are best adapted to the specifics of that system. Historically, changes in agronomic production practices have also brought about substantial changes in the dominant weed species in a community, and thus the herbicides necessary to effectively manage them. For example, as producers adopt conservation tillage practices, there is typically a concomitant increase in the herbicide regime required because tillage is no longer a tool for weed management (Shaw and Rainero 1990; Wrucke and Arnold 1985). Indeed, some soybean producers were initially reluctant to adopt conservation tillage because these systems resulted in an increase in perennial weeds, annual grasses, and small-seeded broadleaf weeds; required more herbicide applications; and eliminated the option of preplant-incorporated herbicides (Buhler et al. 1994; Swanton et al. 1998).

A majority of herbicide-resistant (HR) weed populations have evolved where monoculture use of a single herbicide active ingredient or site of action has occurred (Gressel and Segel 1990). With a cropping system that emphasizes continuous planting, minimal cultivation, and the frequent use of similar herbicides, it is not surprising that resistance has resulted in some common and problematic weed species (Mathews 1994). When declining efficacy of selective herbicides due to resistance occurs, changes in weed management practices must be implemented to reduce yield losses. For example, triazine-resistant weed biotypes were a major problem in corn fields in eastern Ontario, Canada (Stephenson et al. 1990). More than 75% of the corn hectarage was infested with two or more triazine-resistant weed species. Some of the dominant agronomic practices included continuous corn; nearly all fields were treated with atrazine, and the use of POST herbicides was not common. However, in southwestern Ontario, where corn had been grown the longest, triazine-resistant weeds were only a minor problem. In that region, the dominant agronomic practices included crop rotation; atrazine was only used on 60% of the

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corn hectarage, and other POST herbicides were commonly used. The introduction of alternative crops in a crop rotation provides the opportunity to increase herbicide diversity, alter the herbicide application rate, or implement other weed control techniques. These tactics may be effective in reducing the development of HR weeds (Mathews 1994).

With continued use of the same herbicide or site of action, weed species shifts are inevitable (Tingle and Chandler 2004). By removing the more competitive weed species, niches are created for the establishment of new species that were not common previously (Aldrich et al. 1997; Tuesca et al. 2001). Thus, the introduction and use of HR crops was viewed as a valuable new tool to control weeds that were adapted to cropping systems in use at the time of their introduction (Shaw 1995). The incredible popularity of HR crops could be attributed to their effectiveness in weed control, as well as their simplicity and lower cost. When HR crops are grown, producers often apply a single herbicide at a higher rate of active ingredient and at multiple times during the season without concern about crop injury (Owen and Zelaya 2005; Reddy 2001; Shaner 2000). Although a number of HR crops have been developed, the greatest impact on cropping systems has come from the development of GR crops. Glyphosate controls a very broad spectrum of weeds that occur in agricultural, industrial, and domestic situations (Baylis 2000); thus, it is ideally suited as a broad-spectrum POST herbicide in GR crops (Dill 2005). Simplifying weed management without a requirement for tillage as a part of the management program has also allowed producers to implement more conservation tillage practices. This increase has resulted in a reduction in soil erosion and improved soil structure and, with fewer trips across the field, cost saving in fuel and equipment (Baylis 2000). With the expiration of the glyphosate patent in 2000, the proliferation of generic formulations of glyphosate has led to a dramatic decline in glyphosate pricing, making GR cropping systems even more economical (Duke 2005).

With the overwhelming popularity of GR crops, a shift in weed populations to more glyphosate-tolerant species, or the development of GR biotypes, was inevitable. Though weed scientists initially debated how long it would take for glyphosate resistance to evolve in GR cropping systems, it was only 3 yr after the adoption of GR soybean that resistance was identified in horseweed [*Conyza canadensis* (L.) Cronq.] (Owen and Zelaya 2005; VanGessel 2001). To date, 14 weed species have been confirmed worldwide with GR biotypes (Heap 2008). As the planting of GR crops is over 90% in soybean and cotton, and is quickly approaching 50% for corn (Sankula 2006), additional resistant species and biotypes will certainly occur. However, producers will continue to use GR cropping systems even in the presence of GR weeds because of the broad spectrum of other weeds controlled (Dill 2005). Thus, it is imperative to determine how GR cropping systems can be sustained long-term, because much of the agricultural economy is built around the availability and effectiveness of this trait.

Survey information has been used by weed scientists for a number of purposes, including determining perceptions of problem weeds (Gibson et al. 2005; Webster and MacDonald 2001), understanding producer needs (Norsworthy 2003), documenting weed shifts and herbicide resistance development (Bourgeois et al. 1997; Scott and VanGessel 2006), and developing educational programs (Loux and Berry 1991). Because GR crops have been in use for over a decade, the opportunity now exists to document the changes that have occurred in weed management and herbicide use patterns, emerging problematic weed species, and grower perceptions of weed problems in GR cropping systems. This information would be useful to academia and industry so that effective strategies and outreach programs can be developed and tailored that will improve the sustained utilization of GR technology. The overarching objectives of the survey conducted were to determine practices used by producers prior to and after adopting a GR cropping system, any changes in the producers' weed pressure, tillage practices, and herbicide usage pattern in various GR cropping systems, as well as producer awareness of GR weeds and precautions that they are taking to offset the risk of selecting for GR weeds. This paper will provide the introductory and foundational information for the survey, including the entire survey instrument. Additional papers in this series will analyze specific datasets from this extensive survey. The specific objectives for this paper are to understand the diversity of cropping systems associated with GR crops, and determine the characteristics of full-time farming operations that have used GR technology.

Materials and Methods

A survey instrument was designed by the authors (Table 1), and a telephone survey using this instrument was conducted by Marketing Horizons Inc. between November 9, 2005, and January 6, 2006. Producers from six states—Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina—were contacted. 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 Agricultural Products Company, 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 hectares of corn, soybean, or cotton in 2005; and if they planted the GR trait for a minimum of 3 yr. This minimum hectarage was established to ensure that the survey focused on full-time growers rather than those with a small hectarage as a source of secondary income. 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 survey was composed of four sections. Questions in the first section of the survey pertained to crops grown currently and in the past 6 yr. Information was collected on the number of hectares that were planted in the past and would be planted in the coming year, the number of years the GR trait had been

Table 1. Complete instrument for the telephone survey conducted in the winter of 2005/2006 to 356 determine grower perceptions of weed problems and herbicide resistance threat.

A. Are you actively involved in farming?

B. Are you the individual primarily responsible for decisions concerning the seeds, traits, and herbicides purchased for your farming operation?

C. Do you or any member of your household work for a:	Yes	No
Farm chemical manufacturer, distributor, or retailer	(__)	(__)
Seed company in a position other than farmer/dealer	(__)	(__)

D. How many acres of _____ did you plant this year in 2005?

Corn
Soybean
Cotton

E. Did you plant any _____ this year in 2005?
F. [For each "yes"] How many total acres of _____ did you plant this year in 2005?
G. [For each "yes"] Including 2005, for how many years have you been planting _____ ?

		Yes	No	Acres	Years
a.	Roundup Ready soybeans	(_)-1	(_)-2	____	____
b.	Roundup Ready corn – including single- and stacked-trait hybrids	(_)-1	(_)-2	____	____
c.	Roundup Ready cotton – including single- and stacked-trait varieties	(_)-1	(_)-2	____	____

H. I understand it is still several months away, but how many acres of _____ do you plan to plant next year in 2006?

Corn
Soybean
Cotton

[For each crop planting in 2006 >> ask Q.I.]

(continued)

planted, and the number of fields for which the GR trait had been planted for at least the past 3 yr. This information was used to place each producer into one of six groups, described below.

The second section of the survey dealt with weed pressure and tillage practices on a specific, representative field. Producers were asked about the intensity of weed pressure and what weeds were problems for that field prior to the use

I. And, if you were making a decision today, how many acres, if any, of _____ will you plant next year in 2006?

		Acres
a.	Roundup Ready soybeans	_____
b.	Roundup Ready corn – including single- and stacked-trait hybrids	_____
c.	Roundup Ready cotton – including single- and stacked-trait varieties	_____

J. Do you have any fields that have been planted in [Roundup Ready corn, cotton, or soybean] for at least three years?

		Yes	No
a.	Continuous Roundup Ready soybeans	(__)-1	(__)-2
b.	Continuous Roundup Ready corn	(__)-1	(__)-2
c.	Continuous Roundup Ready cotton	(__)-1	(__)-2
d.	A Roundup Ready corn / Roundup Ready soybean rotation	(__)-1	(__)-2
e.	A Roundup Ready cotton / Roundup Ready soybean rotation	(__)-1	(__)-2
f.	A Roundup Ready cotton / Roundup Ready corn rotation	(__)-1	(__)-2
g.	A Roundup Ready soybean / non-Roundup Ready crop rotation	(__)-1	(__)-2
h.	A Roundup Ready corn / non-Roundup Ready crop rotation	(__)-1	(__)-2
i.	A Roundup Ready cotton / non-Roundup Ready crop rotation	(__)-1	(__)-2

J1. [If "yes" to g, h, or i >> ask:] What non-Roundup Ready crop have you rotated in fields with Roundup Ready crop?

a.	Corn	(__)-1
b.	Soybeans	(__)-2
c.	Rice	(__)-3
d.	Sorghum/milo	(__)-4
e.	Peanuts	(__)-5
f.	Wheat	(__)-6
g.	Sunflowers	(__)-7
h.	Barley	(__)-8
i.	Oats	(__)-9
j.	Canola	(__)-10
k.	Other [specify]	

K. [For each "yes":] In how many different fields have you had _____ for at least three years?

a. Continuous Roundup Ready soybeans rotation
b. Continuous Roundup Ready corn rotation
c. Continuous Roundup Ready cotton rotation
d. A Roundup Ready corn / Roundup Ready soybean rotation
e. A Roundup Ready cotton / Roundup Ready soybean rotation

(continued)

f. A Roundup Ready cotton / Roundup Ready corn rotation
g. A Roundup Ready soybean / non-Roundup Ready crop rotation
h. A Roundup Ready corn / non-Roundup Ready crop rotation
i. A Roundup Ready cotton / non-Roundup Ready crop rotation

1. Continuous Roundup Ready soybeans
2. Continuous Roundup Ready corn
3. Continuous Roundup Ready cotton
4. A Roundup Ready corn / Roundup Ready soybean rotation
5. A Roundup Ready cotton / Roundup Ready soybean rotation
6. A Roundup Ready cotton / Roundup Ready corn rotation
7. A Roundup Ready soybean / non-Roundup Ready crop rotation
8. A Roundup Ready corn / non-Roundup Ready crop rotation
9 A Roundup Ready cotton / non-Roundup Ready crop rotation

[NOTE: Ask each grower about a maximum of two crop rotations.]

The questions that follow will focus on your [Roundup Ready corn, cotton, soybean] rotation.

L1. If only one field >> ask: How many acres are in your field that has been planted in [Roundup Ready corn, cotton, soybean] for at least three years?

L2. So we can make sure you are focusing on the same field, do you have a name, number, or other designation that you use to refer to that field, or we can call it field A [or B for second rotation]. (What would that be?)

L1. If more than one field >> ask: In terms of acres, what is the largest field that has been planted in [Roundup Ready corn, cotton, soybean] for at least three years?

L2. So we can make sure you are focusing on the same field, do you have a name, number, or other designation that you use to refer to that field, or we can call it field A [or B for second rotation]. (What would that be?)

<u>New Section Focused Specifically on the Selected Field</u>

1a. How long have you had [Roundup Ready corn, cotton, or soybean] on this specific field or farm?

1b. Using a scale of 1 to 10 where 1 is "very light weed pressure" and 10 is "very heavy weed pressure," how would you describe the weed pressure on the field/farm <u>PRIOR</u> TO starting your rotation of [Roundup Ready corn, cotton, or soybean]?

(continued)

2. And, using the same scale of 1 to 10 where 1 is "very light" and 10 is "very heavy," how would you describe the weed pressure on the field/farm THIS YEAR?

3. What specific weeds, including grasses and broadleaves, were the biggest problems on the field/farm PRIOR TO [Roundup Ready corn, cotton, or soybean]?

4. And, what specific weeds, including grasses and broadleaves, are CURRENTLY the biggest problem on the field/farm following a [Roundup Ready corn, cotton, or soybean] rotation?

5. What has been the biggest challenge, if any, in weed pressure that you have seen on the field/farm since you started a [Roundup Ready corn, cotton, or soybean] rotation?

6. Prior to starting your [Roundup Ready corn, cotton, or soybean] rotation on the field/farm, what was your tillage practice in this field?

7a. And, now what is your tillage practice on this field?

7a1. How long has the field/farm been in [Q.7a]?

7b. [If Q.7a different from Q.6 >> ask:] Why did you change tillage practices on the field/farm since you started a [Roundup Ready corn, cotton, or soybean] rotation?

7c. Has the shift in tillage practices in this field impacted your weed pressure in any way?

I. IF CONTINUOUS ROUNDUP READY SOYBEANS OR ROUNDUP READY CORN OR ROUNDUP READY COTTON:

8a. Did you make a [burndown, preemergence, postemergence application] to your [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

8b. [Ask for each "yes" in Q.8a] What specific herbicides did you apply? Please include any tankmix partners.

a. In the fall of 2004
b. As a preplant burndown application

8c. This year in 2005, how many applications of a glyphosate herbicide, Roundup or some other brand, did you make in-crop or over-the-top of your [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

(continued)

8d. What specific glyphosate herbicide did you apply in your [first/second/third] in-crop or over-the top application in [continuous Roundup Ready corn, cotton, or soybean]?

8e. Did you apply any non-glyphosate herbicides to your [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

8f. What specific non-glyphosate herbicides did you apply? Please include tankmix partners.

8g. When did you apply [brand Q.8f]?

8h. For what specific reason did you use a non-glyphosate herbicide this year in your [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8i. Were you targeting specific grasses and/or broadleaf weeds with this non-glyphosate herbicide?

8j. What specific grasses or broadleaf weeds were you targeting?

9a. Out of the last three years, including 2005, how many years, if any, have you applied a non-glyphosate herbicide to your [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm?

9b. [If "no" to Q.8e and Q.9a 1 or more >> ask:] Why have you used a non-glyphosate herbicide in the past on your [continuous Roundup Ready corn, cotton, or soybean] acres, but not this year?

10a. Over the past three years, what specific changes, if any, have you made to your weed control or herbicide program on the [continuous Roundup Ready corn, cotton, or soybean] planted on the field/farm? This could include changes in tillage practices, herbicide selections, rates, or timing of applications, among others.

10b. Why have you made these changes to your weed control or herbicide program on the [continuous Roundup Ready corn, cotton, or soybean]?

II. IF ROTATING ROUNDUP READY CROPS WITH ROUNDUP READY CROPS:

My next questions will deal with your herbicide program this year in 2005 on the field/farm planted in a [Roundup Ready corn, cotton, or soybean] rotation.

8. What crop did you plant on this field/farm this year in 2005?

(continued)

8a. Did you make a [burndown, preemergence, postemergence application] to your [Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

8b. [Ask for each "yes" in Q.8a] What specific herbicides did you apply? Please include any tankmix partners.

a. In the fall of 2004
b. As a preplant burndown application

8c. This year in 2005, how many applications of a glyphosate herbicide, Roundup or some other brand, did you make in-crop or over-the-top of your [Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

8d. What specific glyphosate herbicide did you apply in your [first/second/third] in-crop or over-the top application in [Roundup Ready corn, cotton, or soybean]?

8e. Did you apply any non-glyphosate herbicides to your [Roundup Ready corn, cotton, or soybean] planted on the field/farm this year? This would include residual herbicides as well as other post-applied herbicides.

8f. What specific non-glyphosate herbicides did you apply? Please include tankmix partners.

8g. When did you apply [brand Q.8f]?

8h. For what specific reason did you use a non-glyphosate herbicide this year in your [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8i. Were you targeting specific grasses and/or broadleaf weeds with this non-glyphosate herbicide?

8j. What specific grasses or broadleaf weeds were you targeting?

9a. Out of the last three years, including 2005, how many years, if any, have you applied a non-glyphosate herbicide to your Roundup Ready crop planted on the field/farm?

9b. [If "no" to Q.8e and Q.9a 1 or more >> ask:] Why have you used a non-glyphosate herbicide in the past on your Roundup Ready crop planted on the field/farm, but not this year?

(continued)

of the GR trait, what the current weed pressure was in that field, and what specific weeds were currently problems. Data on prior and current tillage practices were also collected, as was the number of years that the field had been in the current tillage practice. Producers were asked why they changed tillage practices, if the change in tillage caused any weed shifts, and, if so, in what way.

The third section pertained to herbicide use. Producers were questioned on what herbicides they had used in the past, and what they were presently using. This usage included both

10a. Over the past three years, what specific changes, if any, have you made to your weed control or herbicide program on the Roundup Ready crops planted on the field/farm? This could include changes in tillage practices, herbicide selections, rates, or timing of applications, among others.

10b. Why have you made these changes to your weed control or herbicide program on the Roundup Ready crops planted on the field/farm?

2004 ROUNDUP READY CROP IN A ROUNDUP READY-ROUNDUP READY ROTATION

8a. Did you make a [burndown, preemergence, postemergence application] to your [Roundup Ready corn, cotton, or soybean] planted on the field/farm last year?

8b. [Ask for each "yes" in Q.8a] What specific herbicides did you apply? Please include any tankmix partners.

a. In the fall of 2004
b. As a preplant burndown application

8c. Last year in 2004, how many applications of a glyphosate herbicide, Roundup or some other brand, did you make in-crop or over-the-top of your [Roundup Ready corn, cotton, or soybean] planted on the field/farm last year?

8d. What specific glyphosate herbicide did you apply last year in your [first/second/third] in-crop or over-the top application in [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8e. Did you apply any non-glyphosate herbicides to your [Roundup Ready corn, cotton, or soybean] planted on the field/farm last year? This would include residual herbicides as well as other post-applied herbicides.

8f. What specific non-glyphosate herbicides did you apply? Please include tankmix partners.

8g. When did you apply [brand Q.8f]?

8h. For what specific reason did you use a non-glyphosate herbicide last year in your [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8i. Were you targeting specific grasses and/or broadleaf weeds with this non-glyphosate herbicide?

(continued)

8j. What specific grasses or broadleaf weeds were you targeting?

III. IF ROTATING ROUNDUP READY CROPS WITH NON-ROUNDUP READY CROPS:

My next questions will deal with your herbicide program this year in 2005 on the field/farm planted in a [Roundup Ready corn, cotton, or soybean] rotation.

8. What crop did you plant on this field/farm this year in 2005?

8a. Did you make a [burndown, preemergence, postemergence application] to your [Q.8 crop] planted on the field/farm this year?

8b. [Ask for each "yes" in Q.8a] What specific herbicides did you apply? Please include any tankmix partners.

a. In the fall of 2004
b. As a preplant burndown application

[If Roundup Ready crop in Q.8 >> ask:]

8c. This year in 2005, how many applications of a glyphosate herbicide, Roundup or some other brand, did you make in-crop or over-the-top of your [Roundup Ready corn, cotton, or soybean] planted on the field/farm this year?

8d. What specific glyphosate herbicide did you apply in your [first/second/third] in-crop or over-the top application in [Roundup Ready corn, cotton, or soybean]?

8e. Did you apply any non-glyphosate herbicides to your [Q.8 crop] planted on the field/farm this year? This would include residual herbicides as well as other post-applied herbicides.

8f. What specific non-glyphosate herbicides did you apply? Please include tankmix partners.

8g. When did you apply [brand Q.8f]?

[If Roundup Ready crop in Q.8 >> ask Q.8h.]

8h. For what specific reason did you use a non-glyphosate herbicide this year in your [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8i. Were you targeting specific grasses and/or broadleaf weeds with this non-glyphosate herbicide?

(continued)

8j. What specific grasses or broadleaf weeds were you targeting?

9a. Out of the last three years, including 2005, how many years, if any, have you applied a non-glyphosate herbicide to your field/farm?

9b. [If "no" to Q.8e and Q.9a 1 or more >> ask:] Why have you used a non-glyphosate herbicide in the past on the field/farm, but not this year?

10a. Over the past three years, what specific changes, if any, have you made to your weed control or herbicide program on the crops planted on the field/farm? This could include changes in tillage practices, herbicide selections, rates, or timing of applications, among others.

10b. Why have you made these changes to your weed control or herbicide program on the crops planted on the field/farm?

2004 CROP IN A ROUNDUP READY - NON-ROUNDUP READY ROTATION

8. What crop did you plant on the field/farm last year in 2004?

8a. Did you make a [insert] to your [Q.8 crop] planted on the field/farm last year?

8b. [Ask for each "yes" in Q.8a] What specific herbicides did you apply? Please include any tankmix partners.

a. In the fall of 2003
b. As a preplant burndown application

[If Roundup Ready crop in Q.8 >> ask:]

8c. Last year in 2004, how many applications of a glyphosate herbicide, Roundup or some other brand, did you make in-crop or over-the-top of your [Roundup Ready corn, cotton, or soybean] planted on the field/farm last year?

8d. What specific glyphosate herbicide did you apply last year in your [first/second/third] in-crop or over-the top application in [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8e. Did you apply any non-glyphosate herbicides to your [Q.8 crop] planted on the field/farm last year? This would include residual herbicides as well as other post-applied herbicides.

(continued)

8f. What specific non-glyphosate herbicides did you apply? Please include tankmix partners.

8g. When did you apply [brand Q.8f]?

8h. [If Roundup Ready crop in Q.8 >> ask:] For what specific reason did you use a non-glyphosate herbicide last year in your [Roundup Ready corn, cotton, or soybean] planted on the field/farm?

8i. Were you targeting specific grasses and/or broadleaf weeds with this non-glyphosate herbicide?

8j. What specific grasses or broadleaf weeds were you targeting?

IV. RESISTANCE ISSUES

11a. Are you aware of the potential for weeds to develop resistance to glyphosate herbicides?

11b. Using a scale of 1 to 10 where 1 is "not at all serious" and 10 is "very serious," how serious of a problem do you consider weed resistance to glyphosate herbicides? You may use any number between 1 and 10.

12a. Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?

12b. What specific weeds in your state have been documented as being resistant to glyphosate herbicides?

12c. From what sources have you learned about weed resistance issues related to glyphosate herbicides?

13a. Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?

13b. Which specific grasses or broadleaf weeds?

14a. Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds developing resistance to glyphosate on your farm?

14b. What specific actions are you taking to minimize weed resistance to glyphosate?

(continued)

15. As a way to manage potential glyphosate weed resistance, how effective do you consider [reference each item below individually]? When answering, please use a scale of 1 to 10 where 1 is "not at all effective" and 10 is "very effective."

    a. Rotating herbicide chemistries from one year to the next, for example, not using glyphosate every year
    b. Tillage
    c. Rotating crops
    d. Using the correct label rates of herbicides at the proper timing for the size and type of weeds present
    e. Using more than one herbicide chemistry in a given year, such as glyphosate and a residual herbicide
    f. Using more than one herbicide chemistry in a given year, such as glyphosate and another post-applied herbicide

16. In terms of your farming operation, what are the major obstacles, if any, of [reference each item below individually] as a resistance management approach?

    a. Rotating herbicide chemistries from one year to the next, not using glyphosate every year
    b. Tillage
    c. Rotating crops
    d. Using the correct label rates of herbicides at the proper timing for the size and type of weeds present
    e. Using more than one herbicide chemistry in a given year, such as glyphosate and a residual herbicide
    f. Using more than one herbicide chemistry in a given year, such as glyphosate and another post-applied herbicide

glyphosate- and non–glyphosate-based herbicides. For non-glyphosate herbicides, the timing of application(s) was determined, and the specific reason (or reasons) the herbicide (or herbicides) was or were used. The producers were also asked if they had made any changes to their herbicide program over the past 3 yr and, if so, why these changes were made.

The final section of the survey focused on GR weeds. Producers were asked about 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 those weeds were. They were also asked where they learned about GR weed issues, if they had any personal experience with GR weeds, and, if so, what those weeds were. Finally, producers were asked about what measures, if any, they were taking to minimize the development of GR weeds.

All survey data were entered into a spreadsheet and, if necessary, converted into numerical values for analysis. Data reported in this manuscript focus on the foundation information from the survey regarding the various crop rotations reflected in the survey, and demographics on farm size. In all cases, these values represent averages when the respondent did in fact have that cropping system; in other words, zero values were not entered into the averaging. A chi-square analysis was completed on the data reported in Tables 2 through 4, and reported percentages are significant ($P < 0.05$) unless stated otherwise in the discussion of the data from these three tables.

Results and Discussion

Producers participating in the survey managed 235,000, 38,000, and 236,000 ha of corn, cotton, and soybean in 2005, respectively (data not shown). Of this, 38, 97, and 96%, of their corn, cotton, and soybean hectarage, respectively, were planted in a GR cultivar (data not shown). These high numbers were not surprising, because the survey was based on growers who had signed contracts for the GR trait. Their percentages were higher than national averages for GR cultivar plantings, which were 26, 61, and 87% for corn, cotton, and soybean, respectively, in 2005 (USDA ERS 2008a). Respon-

Table 2. Number of survey respondents with specific cropping systems from each of six states.

Crop rotation	Total	Iowa	Illinois	Indiana	Mississippi	North Carolina	Nebraska
	Number of respondents						
Continuous GR soybean	307	16	31	59	109	79	13
Continuous GR corn	84	25	21	9	1	3	25
Continuous GR cotton	97	—[b]	—	—	47	50	—
GR corn/GR soybean	402	112	82	80	8	19	101
GR cotton/GR soybean	38	—	—	—	13	25	—
GR cotton/GR corn	11	—	—	—	9	2	—
GR soybean/non-GR crop	495	89	105	106	39	69	87
GR corn/non-GR crop	85	25	17	2	—	6	35
GR cotton/non-GR crop	24	—	—	—	7	17	—
Total respondents[a]	1,195	205	201	202	178	207	202

[a] Growers were allowed to respond with up to two crop rotations used in their farm operations. Thus, the sum for the number of responses received for each crop rotation is greater than the number of participating grower respondents (1,195).

[b] Rotation was not used in that state.

dents were fairly evenly divided between the six states by design (Table 2); the survey continued contacting producers from the list until at least 175 responses had been obtained from each state. The majority of farms participating in the survey had continuous GR soybean, GR soybean/GR corn, or GR soybean/non-GR crop as their cropping system. Within the GR soybean/non-GR crop category, the majority of the respondents had either rice or non-GR corn as the rotation with GR soybean. Of particular note were the large differences between states in continuous monocropping systems compared to rotations. The southern states (Mississippi and North Carolina) had a strong majority of the hectarage in continuous monocropping systems, whereas the converse was true with the Midwestern states (Illinois, Indiana, Iowa, and Nebraska). Given the propensity for herbicide-resistance selection pressure to increase under a single monocontinuous cropping system, southern U.S. cropping systems may be especially vulnerable to development of resistance to glyphosate.

Producers using continuous GR soybean and cotton cropping systems had done so for an average of 4.8 and 5.0 yr, respectively (data not shown). This again raises concern, because remaining in the same cropping and herbicide program for a number of years increases selection pressure for resistance development. Producers using a GR soybean/non-GR crop rotation system had done so for an average of 6.4 yr. The GR corn/non-GR crop system had the lowest average time in the system, at 2.9 yr. This would be expected, because GR corn has been available a much shorter time, and adoption has been slower.

The number of hectares in a particular crop varied widely, depending on the crop and rotation scheme used (Table 3). Although our survey was limited to growers that had a minimum of 101 ha (in order to focus on full-time farming operations), production hectarage reported from our survey was comparable to U.S. Department of Agriculture (USDA) data on farm size for each crop in the various regions represented (USDA ERS 2008b). For example, USDA data indicated an average farm size of 352 and 280 ha for corn and soybean, respectively, in the Heartland farm resource region, which encompasses Illinois, Indiana, Iowa, and parts of Nebraska (states relevant to our study). USDA statistics for the Southern Seaboard region (which includes North Carolina) are 270, 362, and 164 ha as average farm sizes for corn, cotton, and soybean, respectively. In the Mississippi Portal region (which includes most of the state of Mississippi) average farm sizes for these crops are 642, 760, and 380 ha, respectively.

Farmers growing corn had more hectarage in GR corn/non-GR crop than any other cropping system questioned (Table 3). Corn growers reported no cotton hectarage in their farming operation, and much less continuous GR soybean than the cropping systems that contained corn in the rotation. Conversely, soybean growers in the survey reported

Table 3. Farm size of survey respondents, evaluated by primary crop and specific cropping system.

	Respondents' primary crop		
Crop rotation	Corn	Cotton	Soybean
	ha (number of respondents)		
Continuous GR corn	367 (84)	—	223 (67)
Continuous GR cotton	—[a]	345 (97)	—
Continuous GR soybean	153 (180)	151 (19)	227 (307)
GR corn/GR soybean	257 (399)	—	210 (397)
GR cotton/GR soybean	94 (13)	208 (32)	188 (35)
GR cotton/GR corn	195 (10)	327 (7)	874 (5)
GR corn/non-GR crop	380 (85)	—	238 (71)
GR cotton/non-GR crop	105 (15)	292 (23)	172 (19)
GR soybean/non-GR crop	238 (461)	231 (5)	213 (495)
Average	237 (995)	296 (128)	211 (1,120)

[a] Growers with this particular crop did not have this cropping system combination.

Table 4. Farm size of survey respondents, evaluated by crop produced and state.

State	Corn	Cotton	Soybean
	ha (number of respondents)		
Illinois	282 (198)	NA[a]	215 (198)
Indiana	264 (196)	NA	246 (202)
Iowa	232 (205)	NA	178 (198)
Mississippi	135 (58)	350 (59)	287 (154)
Nebraska	292 (201)	NA	196 (182)
North Carolina	100 (137)	251 (69)	156 (186)
Average	237 (995)	296 (128)	211 (1,120)

[a] NA, growers from this state did not have this crop.

relatively similar hectarage across all of the cropping systems, when in fact they did have that cropping system in their operation. When looking at the number of respondents in each cropping system category, the number of both corn and soybean growers with either GR corn/GR soybean or a GR soybean/non-GR crop rotation (presumably the majority of which was non-GR corn) was much higher than the other cropping systems. Very few cotton growers reported that they were using any type of a crop rotation system.

Farm-size data were also evaluated by state for each crop (Table 4). Overall, these data again were fairly comparable to USDA farm-size data broken down by crop and region of the United States (USDA ERS 2008b). Another comparison that could be made would be USDA data on average farm size by state (regardless of land use). For the six states in this study, farm sizes averaged 151, 101, 142, 106, 376, and 68 ha for Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina, respectively (USDA ERS 2008c). This latter data set includes minor crops and farms with small hectarage in which the primary income is generated outside the farming operation. Our survey was focused on information generated from full-time farming operations.

In our survey, corn growers in Mississippi and North Carolina had substantially smaller hectarage of corn compared to the other states (Table 4). Conversely, soybean growers in Mississippi had the largest farm sizes for that crop of any of the six states. As expected, growers in only Mississippi and NC reported cotton hectarage, with farms substantially larger in Mississippi than in North Carolina. Farm sizes for all three crops were smallest in North Carolina. These data are confirmed by USDA statistics as well. When looking at the number of respondents by crop from each state, Mississippi had far fewer corn growers than any other state surveyed, followed by North Carolina (Table 4). The others states were fairly equal in number, and almost all respondents from those states had corn hectarage in their farming operation (Tables 2 and 4). This was similarly true with soybean. Thus, the potential for crop rotations is fairly strong throughout all six states in this study. Crop rotation is one of the strongest opportunities for herbicide resistance management, because this usually opens up a number of new agronomic practices and herbicide options. Conversely, our data also indicate a heavy reliance on GR traits in all of the crops reported in our survey, which negates many of the advantages that crop rotation provides.

This survey generated a number of practical questions regarding the best management practices for managing weed shifts toward species or biotypes more tolerant to glyphosate. As a follow-up to the survey (but not reported in this paper), long-term field studies have been initiated that will develop paired comparisons between grower practices vs. academic recommendations for effective resistance management. The academic recommendations will focus on following herbicide resistance management practices, primarily the inclusion of herbicides with other sites of action, particularly residual herbicides at planting.

Based on producer responses, five groupings of cropping systems were developed for the long-term field studies that are planned: continuous GR soybean, continuous GR cotton, GR corn/GR soybean rotation, GR soybean/non-GR crop rotation, and GR corn/non-GR crop rotation (Table 2). Four states—Illinois, Indiana, Mississippi, and North Carolina—had analyzable numbers of the continuous GR soybean system. Mississippi and North Carolina are the only states to contain the continuous GR cotton system. The four Midwestern states (Illinois, Indiana, Iowa, and Nebraska) had sufficient numbers of the GR corn/GR soybean rotation for consideration, and all six states had sufficient numbers of the GR soybean/non-GR crop rotation for analysis (although differences occurred in the specific non-GR crop in the rotation). Nebraska is the only state to have the GR corn/non-GR crop rotation in sufficient numbers in the survey for analysis. Each state selected the top four groupings from that state as the basis for field selection for the long-term field studies that are to follow. Six fields with a minimum of 16 ha in size were selected per category, and the fields were divided equally between grower practice and academic recommendation. Results of these studies will be reported in future papers.

As can be noted from the survey questions in Table 1, a large volume of data were generated from the survey. Results from various sections of the survey have been analyzed separately, and are reported in the three papers immediately following this manuscript, as well as in additional papers yet to be developed.

The survey information reported here provides a good sense of the diversity of cropping systems utilized by growers that use the GR trait in their agronomic program. It also highlights the challenges and opportunities in using this trait: challenge from the standpoint of the heavy reliance on a single trait and herbicide for weed management; opportunity from the standpoint of the wide range of cropping systems and thus varying weed management practices to minimize the chances of development of glyphosate resistance. Weed scientists must use this information to capitalize on these opportunities and effectively provide information on best management practices for sustainable weed management, including the complete range of management strategies that can be brought to bear.

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