Shifts in herbicide use, tillage practices, and perceptions of glyphosate-resistant weeds following adoption of glyphosate-resistant crops

Wade Alexander Givens

SHIFTS IN HERBICIDE USE, TILLAGE PRACTICES, AND PERCEPTIONS OF GLYPHOSATE-RESISTANT WEEDS FOLLOWING ADOPTION OF GLYPHOSATE-RESISTANT CROPS

By

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A survey was conducted by phone to nearly 1,200 growers in six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina) in 2005. The survey measured producers' cropping history, perception of glyphosate-resistant (GR) weeds, past and present weed pressure, tillage practices, and herbicide use as affected by the adoption of GR crops. The objectives of this study were to determine the effect of GR crop use on producers' tillage practices; changes in herbicide use patterns after adoption of a GR crop; effect of grower awareness of GR weeds on sources of information growers' use; and growers' perceptions on resistance management based on knowledge of GR weeds in their farming operation.

The adoption of GR cropping systems contributed to large increases in the percentage of growers using no-till and reduced-till systems. Tillage intensity declined more in continuous GR cotton and GR soybean (45 and 23%, respectively) than in rotations that included GR corn or non-GR crops. Tillage intensity declined more in the states of Mississippi and North Carolina than in the other states, with 33% of the growers in these states shifting to more conservative tillage practices after the adoption of a GR crop. This was in part due to the lower amount of conservation tillage adoption in these

states prior to GR crop availability.

With respect to herbicide use patterns, frequently used herbicides for fall applications were 2,4-D and glyphosate; these herbicides were often used for preplant, burndown weed control in the spring. As expected, crop rotations using GR crops had a high percentage of respondents that made one to three POST applications of glyphosate per year. Overall, glyphosate use has continued to increase, with concomitant decreases in utilization of other herbicides.

Concerning grower awareness of GR weeds and perceptions of resistance management in 2005, the majority of the growers (88%) were aware of a weed's potential to develop resistance to glyphosate, while 44% were aware of state-specific, documented cases of glyphosate weed resistance. Growers that have had experience with GR weeds were more knowledgeable about resistance management practices that could be used to mitigate them.

DEDICATION

I would like to dedicate this work to my wife, Abbie, and our children. When she supported me through a Master's degree I attributed it up to naivety. When she continued to support me through a Ph.D., I called it madness. Through all this she has tirelessly raised two children while I spent many a night away from home working or writing, and I know they have sacrificed because of it. They really should give honorary degrees to the spouses of Ph.D. candidates.

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I also thank the other members of my committee, Dr. John Byrd, Dr. Trey Koger, Dr. John Madsen, and Dr. Michael Newman. It has been a joy and a privilege to learn from these individuals. They have challenged me, and made sure that above all, I was a weed scientist first. Time has taught me the wisdom in this. I also thank the Monsanto Company for funding what will most certainly be known as foundational research in the area of herbicide resistance and its impact on the agricultural landscape. I also extend a special thanks to Jason Weirich and Jonathan Huff for the countless hours on the road and in the field spent working on this benchmark study, and will never forget the night we told Edwards he would have to sleep in the truck. I wish both Jason and Jonathan the best in all of their future endeavors.

I also thank my wife, Abbie, for all of her love and support. Without her encouragement, I truly would not be where I am today. She has been there to keep pushing through the times when I just wanted to sit down. She has selflessly given of her time and energy in support of this endeavor, and still managed to raise two children who teach me something new every day.

Last, but not least, I like thank the Lord above, without whom none of this would have been possible.

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CHAPTER I

INTRODUCTION

Glyphosate was introduced to the market in the early 1970's and quickly became very popular because of its broad spectrum of weed control. Its systemic nature meant control of many perennial weeds as well. Glyphosate has become one of the world's leading agrochemicals (Woodburn 2000). During the 1970s and early 1980s, research explored means of breeding herbicide resistance into crops (Barrentine et al. 1982). However, it was not until the 1980s that the tools for developing genetically engineered, transgenic crops became available. Several companies saw the advantage of using these technologies to produce transgenic crops that would be tolerant to non-selective herbicides. Extensive efforts were put forth to develop glyphosate-resistant (GR) crops, eventually leading to the use of the CP4 gene from *Agrobacterium* sp. This bacterium encodes a glyphosate-resistant form of 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS) (Padgette et al. 1995).

The first commercially available GR crop was soybean [*Glycine max* (L.) Merr.] in 1995. GR cotton (*Gossypium hirsutum* L.) followed in 1997, and GR corn (*Zea mays* L.) was introduced in 1998. In 2005, over 90% of the total U.S. soybean and cotton hectares, along with nearly 50% of the corn hectares, contained a herbicide-tolerant gene (Sankula 2006). Adoption of these technologies has been rapid due to improved spectrum weed control, more convenient weed management systems, and reduced time and labor inputs (Ateh and Harvey 1999; Bradley et al. 2004; Corbett et al. 2004;

Culpepper et. al 1999; Faircloth et al. 2001; Johnson et al. 2000; Reddy and Whiting 2000; Thomas et al. 2004a, 2004b).

Weed control in agricultural fields is a concern for which many producers spend a great deal of time addressing year after year. Before the introduction of commercial herbicides, tillage became synonymous with seedbed preparation and post-emergence weed control (Reicosky and Allmaras 2003). Without other effective means for controlling pests, tillage was important, not only for weed control, but also insect and disease management, and management of crop residue. Since the early 1920's there have been advocates for the reduction of tillage (Graber 1928). Even early on, the detrimental effects of tillage to the landscape were beginning to be understood. Soil erosion and runoff of pesticide residues and nutrients can be substantially reduced by the adoption of reduced tillage practices (Fawcett et al. 1994, Karlen et al. 1994, Smart and Bradford 1999, Swanton and Weise 1991). Likewise, reduced-till systems have the potential to decrease input costs because of fewer tillage operations (CTIC 2006). Despite the negative impacts of tillage, it remained an important tool in the management of vegetation prior to the planting of crops because it reduced the number of annual weeds (Gunsolus 1990; Stoller and Wax 1973). Tillage was also beneficial in cropping systems involving perennial crops. It was used to destroy the perennial crop prior to the seeding of annual crops (Tripplett 1985). With the introduction of 2,4-D in the mid-1940's growers were, for the first time, given an economic alternative to pre-plant tillage. (Burnside 1996). The introduction of 2,4-D ushered in a new era in which producers had a viable alternative to tillage for weed control (Burnside, 1996). Over the following decades there was an explosion of herbicide discovery that changed the way farmers dealt with weed management. During this time of herbicide discovery, several non-selective herbicides were also brought to market, including paraquat, glufosinate, and glyphosate. This culminated with the introduction of GR crops. GR crops allowed growers to apply glyphosate post-emergence to manage weeds, which in turn allowed growers to replace tillage with selective herbicides as a more economical method for weed control.

With nearly a decade of GR cropping system usage, one would expect significant changes in herbicide use, both specific compounds used and amount of use, as well as shifts in tillage practices. Several researchers have investigated herbicide use patterns following GR crop adoption by examining existing datasets such as the National Agricultural Statistics Service chemical use databases and other industry-compiled databases (Shaner 2000; Young 2006). An overall reduction in the amount of herbicides applied was noted since grower adoption on GR cropping systems, as was a heavy reliance on glyphosate in their weed management programs. These data are very useful, but a database targeted to address specific questions on herbicide use after GR crop adoption would provide additional insights.

One means of collecting data on actual usage and grower perceptions about weed management is through grower surveys. These types of surveys have been used in the past to document changes in management practices and grower perceptions to potential problems in a wide range of areas, from irrigation practices to perceptions about insect pressure and pesticide use (Dillard 1993; Snyder 1996). Grower surveys have been especially important to weed science and have allowed scientists to gain insight on a number of grower perceptions and practices. Examples include herbicide use and grower perceptions of issues such as herbicide resistance in weeds and herbicide-resistant crop use (Charles 1991; Gibson et al 2005; Gibson et al. 2006; Johnson and Gibson 2006; Llewellyn et al. 2002). By using grower surveys, weed scientists have the opportunity to capture a cross-section spanning different states and their crop rotations after implementing a GR crop into their cropping systems.

It is also important to document how exposure to GR weeds may alter a grower's perception on glyphosate resistance management and the sources of information growers turn to concerning glyphosate resistance issues. Data collected from the survey will be analyzed to quantify the differences in perceived "best" management practices with respect to GR weeds based on whether a grower has had exposure to GR weeds or not. Responses to obstacles to these resistant management strategies will also be analyzed.

The objectives of the studies reported in the following chapters are to: (1) determine and quantify the effect of GR crop use on producers' tillage practices, (2) to determine changes in herbicide use patterns after adoption of a GR crop, (3) determine effect of grower awareness of GR weeds on sources of information growers use, and (4) compare growers' perceptions on resistance management based on presence or absence of GR weeds in their farming operation.

The Survey

A survey instrument was designed by researchers for use in the six states that were the focus of this study (see Shaw et al. 2009 for more details of the survey). A telephone survey using this instrument was conducted by contacting producers from Iowa (IA), Illinois (IL), Indiana (IN), Mississippi (MS), North Carolina (NC), and Nebraska (NE). Across these six states, the producers who responded represented 235,000, 236,000, and 38,000 ha of corn, soybean, and cotton planted in 2005, respectively, with 38, 96, and 97% planted in a GR crop. The survey consisted of four sections dealing with different aspects of their farming practices. Specific questions can be found in

Table 1.1. The sections dealt specifically with cropping history, weed pressure and tillage practices, herbicide use, and GR weeds. The respondents were asked to focus their answers on one specific representative field for each cropping system.

The second section of the survey dealt with the weed pressure and tillage practices use on a specific, representative field. Objective 1 of this dissertation focuses on the tillage information found in this section. Questions in this section address what tillage system growers were using before and after their adoption of GR cropping technologies.

For Objective 1, the cropping systems analyzed included continuous GR soybean, continuous GR cotton, GR corn/GR soybean rotation, GR soybean/non-GR crop rotation, and GR corn/non-GR crop rotation. Marginal homogeneity tests were performed to test for significant changes in tillage before and after GR crop adopting. Marginal homogeneity is the likelihood that a producer remains in a particular tillage system after the adoption of a GR crop. Data were tested overall for marginal homogeneity, and then tested by each crop rotation, state, and farm size (small, medium, and large). Farm size categories were determined by the hectares in production for each grower with <220 ha = small, 220 to 440 ha = medium, and >440 ha = large.

For multiple comparisons tests, a change variable was calculated to determine if farm size, crop rotation or state affected the change in tillage practice. Each tillage system was coded from “1” to “3”, with no-till receiving a value of “1”, reduced-till receiving a value of “2”, and conventional tillage receiving a value of “3”. The difference was calculated by subtracting the tillage after GR crop adoption from tillage before GR crop adoption. The GLM procedure in SAS[1] was used on the absolute value of the

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[1] SAS, Version 9.2, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

change variable to separate the means at the 0.05 significance level for each set of analyses.

For Objective 2, only the following crop rotations are discussed: continuous GR corn, continuous GR soybean, continuous GR cotton, GR corn/GR soybean rotation, GR cotton/GR soybean rotation, GR soybean/non-GR crop rotation, and GR corn/non-GR crop rotation. Data for this objective were generated from questions 8a – 8g of the survey (Table 1). Grower responses to herbicide application timing and frequency were calculated for each cropping system. Each application timing was further investigated to examine the most frequently used herbicides for each application timing. Glyphosate use by application timing was examined for each crop rotation.

For Objective 3, the questions used for analysis and discussion included questions 11a, 12a, 12c, and 13a, from the survey (Table 1.1). Questions 11a, 12a, and 13a investigated grower awareness of weeds potential to develop resistance to glyphosate herbicide, grower awareness of documented resistance in their state, and grower personal experience with GR weeds, respectively. Question 12c probed the growers to list the sources information they use to learn about weed resistance issues related to glyphosate herbicides. Chi-square analyses were performed on the reported sources of information by the responses to each of the three questions dealing with grower awareness to glyphosate resistance.

Objective 4 in this study was to compare and contrast growers' perceptions on resistance management based on presence or absence of GR weeds in their farming operation, and utilized the growers' responses from questions 13 – 16. These data were categorized based on whether or not the grower has had experience dealing with GR weeds on their farm. The categorized data were summarized by state and crop rotation.

Responses to resistance management strategies for each category were summarized and examined for differences based on grower experiences with GR weeds.

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Table 1.1. Questions from the survey conducted in the winter of 2005/2006 to determine grower perceptions of weed problems and herbicide resistance threat.

1a. How long have you had [trait] 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 [name] field/farm PRIOR TO starting your rotation of [trait]?

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 [name] field/farm THIS YEAR?

3. What specific weeds, including grasses and broadleaves, were the biggest problem on the [name] field/farm PRIOR TO [trait]?

4. And, what specific weeds, including grasses and broadleaves, are CURRENTLY the biggest problem on the [name] field/farm following a [trait] rotation?

5. What has been the biggest challenge, if any, in weed pressure that you have seen on the [name] field/farm since you started a [trait] rotation?

6. Prior to starting your [trait] rotation on the [name] 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 [name] field/farm been in [Q.7a]?

7b. [If Q.7a different from Q.6 >> ask:] Why did you change tillage practices on the [name] field/farm since you started a [trait] 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 [insert] to your [continuous Roundup Ready soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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

(continued)

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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 [continuous Roundup Ready soybeans /Roundup Ready corn / Roundup Ready cotton]?

8e. Did you apply any non-glyphosate herbicides to your [continuous [Roundup Ready soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] field/farm?

9b. [If “no” to Q.8g and Q.9a 1 or more >> ask:] Why have you used a non-glyphosate herbicide in the past on your [continuous Roundup Ready soybeans /Roundup Ready corn / Roundup Ready cotton] 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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready

(continued)

Table 1.1 (continued)

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

8. My next questions will deal with your herbicide program this year in 2005 on the [name] field/farm planted in a [trait] rotation.

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

8a. Did you make a [insert] to your [Roundup Ready soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton]?

8e. Did you apply any non-glyphosate herbicides to your [Roundup Ready soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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?

(continued)

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 [name] field/farm?

9b. [If "no" to Q.8g 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 [name] field/farm, but

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 [name] 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 [name] field/farm?

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

8a. Did you make a [insert] to your [Roundup Ready soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] field/farm?

8e. Did you apply any non-glyphosate herbicides to your [Roundup Ready soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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. For what specific reason did you use a non-glyphosate herbicide last year in your [Roundup Ready soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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?

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

8. My next questions will deal with your herbicide program this year in 2005 on the [name] field/farm planted in a [trait] rotation.

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

8a. Did you make a [insert] to your [Q.81 crop] planted on the [name] 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.81 >> 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 soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton]?

8e. Did you apply any non-glyphosate herbicides to your [Q.81 crop] planted on the [name] field / farm this 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]?

[If Roundup Ready crop in Q.81 >> ask Q.8h.]

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

9b. [If “no” to Q.8g and Q.9a 1 or more >> ask:] Why have you used a non-glyphosate herbicide in the past on the [name] 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 [name] 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 [name] field/farm?

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

81. What crop did you plant on the [name] field/farm last year in 2004?

8a. Did you make a [insert] to your [Q.81 crop] planted on the [name] 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

(continued)

Table 1.1 (continued)

[If Roundup Ready crop in Q.81 >> 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 soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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 soybeans /Roundup Ready corn / Roundup Ready cotton] planted on the [name] field/farm?

8e. Did you apply any non-glyphosate herbicides to your [Q.81 crop] planted on the [name] 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. [If Roundup Ready crop in Q.81 >> ask:] For what specific reason did you use a non-glyphosate herbicide last year in your [Roundup Ready soybeans / Roundup Ready corn / Roundup Ready cotton] planted on the [name] 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?

(continued)

Table 1.1 (continued)

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?

15. As a way to manage potential glyphosate weed resistance, how effective do you consider _____ ? 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 _____ 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

CHAPTER II

SURVEY OF TILLAGE TRENDS FOLLOWING THE ADOPTION OF GLYPHOSATE RESISTANT CROPS

Abstract

A phone survey was administered to 1,195 growers in six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina). The survey measured producers' crop history, perception of glyphosate-resistant (GR) weeds, past and present weed pressure, tillage practices, and herbicide use as affected by the adoption of GR crops. This paper describes the changes in tillage practice reported in the survey. The adoption of a GR cropping system resulted in a large increase in the percentage of growers using no-till and reduced-till systems. Tillage intensity declined more in continuous GR cotton and GR soybean (45 and 23%, respectively) than in rotations that included GR corn or non-GR crops. Tillage intensity declined more in the states of Mississippi and North Carolina than in the other states, with 33% of the growers in these states shifting to more conservative tillage practices after the adoption of a GR crop. This was in large part due to the lower amount of conservation tillage adoption in these states prior to GR crop availability. Adoption rates of no-till and reduced-till systems increased as farm size decreased. Overall, producers in a crop rotation that included a GR crop shifted from a relatively more tillage-intense system to reduced-till or no-till systems after implementing a GR crop into their production system.

Introduction

Tillage has been an integral part of production agriculture, and is synonymous with seedbed preparation and postemergence weed control (Reicosky and Allmaras, 2003). Tillage has also been important for insect and disease management through the burial of crop residue. Since the early 1920's, there have been advocates for the reduction of tillage (Graber 1928). As the use of commercial fertilizers and pesticides began to increase, advocates began to cite the detrimental effects of tillage to the landscape such as soil erosion and runoff of pesticide residues and mineral nutrients as reasons to adopt reduced tillage (Fawcett et al. 1994, Karlen et al. 1994, Smart and Bradford 1999, Swanton and Weise 1991). Reduced-tillage systems also have the potential to decrease input costs because of fewer tillage operations (CTIC 2006).

Despite the negative environmental effects of tillage, it remained an important tool for managing weeds prior to the planting of crops and after their emergence, but before full crop canopy (Gunsolus 1990; Stoller and Wax 1973). Tillage was used to destroy perennial crops prior to seeding annual crops (Tripplett 1985). With the introduction of 2,4-D in the mid-1940's, producers were for the first time given an economical chemical alternative to tillage for pre-plant weed control (Burnside, 1996). The introduction of numerous other herbicides in the succeeding decades allowed reduced and conservation tillage systems to become more feasible and popular. The introduction of glyphosate-resistant (GR) crops in 1996 brought a technology that enabled many producers to adopt reduced tillage production systems.

Glyphosate controls a broad spectrum of broadleaf and grass weeds (Burke et al. 2005; Corbett et al. 2004, Culpepper and York 1998; Grossbard and Atkinson 1985; Wilcut and Askew 1999; Wilcut et al. 1999). In 2005, over 90% of the total U.S. soybean and cotton crops produced, along with nearly 50% of corn, contained a herbicide-tolerant gene (Sankula 2006). In 2003, global use of herbicide-tolerant soybean reached 60% (James 2005). The introduction of GR crops allowed producers to apply glyphosate postemergence as an effective tool for weed management. The use of glyphosate for weed control quickly began to replace preplant tillage and postemergence cultivation, as well as other selective herbicides as a more economical method of weed control.

Grower surveys have been used in the past to document changes in management practices and grower perceptions to potential problems. Issues that surveys have measured include irrigation practices, insect pressure, pesticide use, and herbicide resistant weeds and the use of herbicide resistant crops (Dillard 1993; Snyder 1996). Grower surveys have been especially important to weed science, in that they have allowed scientists to gain insight on a number of grower perceptions and practices. Examples include grower herbicide use and grower perceptions of items such as herbicide resistance in weeds and herbicide-resistant crop use (Charles 1991; Gibson et al 2005; Gibson et al. 2006; Johnson and Gibson 2006; Llewellyn et al. 2002).

It has been a decade since the introduction of the first GR crop. During this time, herbicide use patterns have changed as growers have learned to optimize weed management with this technology. Shifts in weed species and biotypes have been observed, and growers’ use of tillage has changed. The purpose of this paper is to document the effect of GR crop use on producer’s tillage practices. The data for this paper is a subset from a dataset generated from a telephone survey of 1,195 producers in six states that was conducted between November 9, 2005 and January 6, 2006 (Shaw et al. 2009).

Materials and Methods

The survey was developed by a team of weed scientists, and was used in a telephone survey of producers from Iowa (IA), Illinois (IL), Indiana (IN), Mississippi (MS), North Carolina (NC), and Nebraska (NE). A total of 1,195 producers were surveyed (~200 per state). The survey consisted of four sections: cropping history, weed pressure and tillage practices, herbicide use, and GR weeds. Respondents were asked to focus their answers on one specific representative field. Complete details on the survey, including the methodology used, are reported in an introductory paper for this series by Shaw et al. (2008). This paper will focus on the tillage practice data generated from the weed pressure and tillage section of the survey, in particular, what tillage practices were used before and after the adoption of GR crops.

SAS[1] was used to test for marginal homogeneity using the procedure CATMOD. This procedure is a different technique for doing categorical data analysis that is based on the transformation of cell probabilities. Marginal homogeneity, in context of this study, is the likelihood that a producer remains in a particular tillage system after the adoption of a GR crop. Data were tested overall for marginal homogeneity, and then tested by each crop rotation, state, and farm size (small, medium, and large). Farm size categories were determined by the hectares in production for each grower with <220 ha = small, 220 to 440 ha = medium, and >440 ha = large.

For multiple comparisons tests, a change variable was calculated to determine if farm size, crop rotation or state affected the change in tillage practice. Each tillage system was coded from “1” to “3”, with no-till receiving a value of “1”, reduced-till receiving a value of “2”, and conventional tillage receiving a value of “3”. The difference was calculated by subtracting the tillage after GR crop adoption from tillage before GR

[1] SAS, Version 9.2, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

crop adoption. The values for the change variable are presented in Table 2.1. The GLM procedure in SAS was used on the absolute value of the change variable to separate the means at the 0.05 significance level for each set of analyses.

Results and Discussion

Change in Tillage Practice after Adoption of GR Crop

A large percentage of growers surveyed shifted toward reduced-till or no-tillage systems after adopting GR crops as part of their crop rotation. Of producers who had been in conventional tillage, 25% transitioned to no-till, and 31% transitioned to reduced-till systems after adopting GR crops (Table 2.2). Twenty five percent of producers who had been in reduced-till systems converted to no-till, and 74% remained in reduced-till after adopting GR crops. The majority (92%) of producers that were in a no-till system prior to GR crop introduction remained in a no-till system after their implementation of a GR cropping system. Each tillage system differed from the other with respect to the amount of change after adopting a GR crop, with growers in conventional tillage having the largest amount of change after adopting a GR crop.

Changes in Tillage System as Affected by Cropping System

Marginal homogeneity tests demonstrated significant effects by cropping systems on the change of tillage practices. Data in Table 2.3 show that farmers in all cropping systems increased their use of conservation tillage systems after adopting GR crops. The largest decline in conventional tillage occurred in continuous GR cotton with 46% of the growers in conventional tillage systems shifting to reduced- or no-till systems (Table 2.3). These results agree with reports from Gianessi (2005) and Toley (2002), in that cotton producers made fewer tillage operations after planting GR cotton. Cotton producers were often reluctant to adopt reduced- or no-till prior to the introduction of GR cotton because of low yields and poor quality due to early-season weed competition (Derting 1990). An integrated program that used tillage and preemergence herbicides was typically the only means of successful weed control and maximized returns (Barnes and Whitmore 1990; Keeling and Abernathy 1989). Thus, conservation tillage adoption in cotton had been low, which also meant that the opportunity for adoption was greatest when an effective weed control tool such as a GR system became available. These data clearly demonstrate that cotton producers were quite willing to adopt conservation tillage when there was a means of effectively controlling weeds, especially when it was a tool as simple as glyphosate postemergence.

Continuous GR soybean had the next highest adoption rates of conservation tillage practices, with 23% of the growers in conventional tillage systems shifting to reduced- or no-till systems (Table 2.3). Weed control in no-till cropping systems is dependent on effective postemergence options for weed control (Kapusta and Krausz 1993). The introduction of selective broadleaf herbicides such as chlorimuron, imazaquin, and imazethapyr gave growers more effective postemergence options for weed control. Postemergence grass herbicides such as sethoxydim, fluazifop, and quizalofop came to market soon after, but their use was somewhat limited due to price and antagonism when tank mixing with the broadleaf herbicides (Pike et al. 1991; Krumm and Martin 1999). With the introduction of GR soybean in 1996, growers were able to use a single, wide-spectrum material for weed control, enabling rapid adoption of no-till systems. Between 1990 and 2000, no-till acreage rose from 6,474,980 hectares to 21,043,690 hectares, an increase of 225% (CTIC 1999).

Growers in GR soybean/non-GR crop rotations reported a shift of 17 and 39% to no - and reduced-tillage, respectively (Table 2.3). GR technology has enabled many producers to remove fall and spring tillage practices from their management operations, and use herbicides exclusively for weed control. This finding is supported by Moseley and Hagood (1990), who found that glyphosate provided effective control of weeds before crop emergence. With an economical alternative to tillage, preplant tillage operations can justifiably be replaced with a herbicide treatment to remove winter annuals prior to planting. This can make conservation tillage practices more feasible.

In the corn production systems, the change in tillage practice from conventional till to no-till or reduced-till were lower (12 and 11%, respectively) (Table 2.3). Many of the growers in corn production systems had already adopted conservation tillage practices. Growers in 76% of GR corn / non-GR crop rotations, 73% of GR corn / GR soybean rotations, and 63% of GR soybean/ non-GR crop rotations where already using conservation tillage practices before the adoption of a GR crop into their rotations.

Many portions of the Corn Belt's topography ranges from level to gently rolling to hilly, heavily dissected landscapes. This region falls into the 30% of the nation's cropland in which soil erosion is the dominant limitation in agricultural production. This cropland's potential contribution to watershed sediment yield is very high (USDA-ARS 1975). In response, conservation efforts were targeted in these areas, and from 1973 to 1981, the number of reduced-till hectares increased 125%, and no-till planting increased 78% (Christensen and Magleby 1983). These areas were using conservation tillage practices prior to the introduction of GR crops.

Changes in Tillage System as Affected by State

The states with the highest percentage of growers shifting from conventional tillage to reduced-till and no-till was Mississippi and North Carolina; 33% of growers from each state shifting to more conservation tillage practices after adopting a GR crop into their crop rotations (Table 2.4). In Mississippi, 22 and 41% of the growers in conventional tillage systems shifted to no-till and reduced-till, and in North Carolina, 39 and 22% of growers in conventional tillage shifted to no-till and reduced-till. These states were also areas of cotton and soybean production in the survey. Results from the crop rotation analysis indicated that areas in continuous GR cotton production had the highest shifts from conventional tillage to reduced- and no-till systems. This, coupled with the continuous GR soybean production in these two states, and the large percentage of growers in conventional tillage before GR crop adoption (62% in MS and 53% in NC) validates the results of the tillage system change by state analysis.

Nebraska, Indiana, Illinois, and Iowa also saw an increase in the percentage of growers adopting reduced-till and no-till practices with increases of 17, 14, 12, and 11% respectively (Table 2.4). These states are major corn producing states. These results are in agreement with those of the crop rotation analysis in that the lowest adoption of conservation tillage practices occurred within rotations that contained GR-corn or conventional corn. Of the corn producing states, Nebraska had the highest percentage of growers adopting conservation tillage practices, with 49 and 46% of the growers in conventional tillage shifting to no-till and reduced-till, respectively.

A topic of interest is the fact that Nebraska, Iowa, Indiana, and Illinois also had the highest percentages of growers using no-till and reduced-till practices before the adoption of a GR crop. Seventy eight percent of growers in Nebraska, 75% of growers in Iowa, 72% of growers in Indiana, and 61% of growers in Illinois were using conservation tillage practices prior to the adoption of GR crops into their crop rotations. The previous analysis indicated that crop rotations containing corn had higher percentages of growers using conservation tillage practices before adopting a GR crop. Reasons for this are discussed in the previous section.

Changes in Tillage System as Affected by Farm Size

The largest reduction in conventional tillage came from producers with smaller farms, with 30 and 25% of growers shifting from conventional tillage to no-till and reduced-till respectively (Table 2.5). One possible reason for this high rate of adoption is that GR crops have enabled producers to eliminate tillage trips across the fields and control weeds using glyphosate versus preemergence and selective herbicides in season, resulting in a savings to the producer. Taking into account the decrease in the number of small farms, no-till has the capacity to be a vital tool to keep production agriculture a viable enterprise for small farm operators because of its potential to lower labor input and overall production costs (Smart and Bradford 1999). Production practices that growers with small farms can readily recognize will result in a cost savings are usually implemented quickly. In contrast, research conducted by Fernandez-Cornejo et al. (2001) found that, for site-specific technologies and agro-biotechnologies, small farmers were less likely to adopt these technologies because of the higher perceived risk.

GR cropping systems have become very popular over the past decade. This survey gives beneficial insight into how these systems impact producers' tillage management systems. In particular, large percentages of producers reduced tillage intensity after implementing a GR cropping system by adopting no-till or reduced-tillage cropping systems. Important environmental benefits, such as reduced soil erosion and reduced energy consumption by tillage operations have been experienced because of the introduction of GR technology. It is imperative that we understand the impacts of different weed management strategies as weed management programs are adjusted over time. Data such as these aid researchers in understanding the long-term environmental and ecological impacts of GR cropping systems as well as the socio-economical reasons which dictate growers' management decisions.

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Table 2.1. Answer matrix showing computation of change variable. The change variable is used in all corresponding analyses.

Tillage Before	Value Assigned	Tillage After	Value Assigned	Equation	Change Value
Conventional Tillage	3	No-Till	1	3 – 1	2
Conventional Tillage	3	Reduced-Till	2	3 – 2	1
Reduced-Till	2	No-Till	1	2 – 1	1
Conventional Tillage	3	Conventional Tillage	3	3 – 3	0
Reduced-Till	2	Reduced-Till	2	2 – 2	0
No-Till	1	No-Till	1	1 – 1	0
No-Till	1	Reduced-Till	2	1 – 2	-1
Reduced-Till	2	Conventional Tillage	3	2 – 3	-1
No-Till	1	Conventional Tillage	3	1 – 3	-2

Table 2.2. Analysis of survey data highlighting shifts in tillage systems from before to after implementation of a glyphosate-resistant (GR) cropping system, averaged across states and cropping systems. Individual values represent the current distribution (in percent) among the tillage practices for farms which originated in each of the three tillage system (before implementation of GR crops). Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. All changes in tillage practices were significant at the 0.05 level.

Tillage System Before GR Crop	Tillage System After GR Crop				
	No-Till	Reduced-Till	Conventional Till	Total	Separated Means[ab]
	--------% (number of responses)--------				
Conventional Till	25(119)	31(150)	44(214)	37(483)	a
Reduced-Till	25(122)	74(365)	2(9)	38(496)	b
No-Till	92(293)	6(18)	3(8)	25(319)	c
Total	41(534)	41(533)	18(231)	100(1298)[c]	

[a] Tillage practices before GR crop adoption sharing the same letter(s) are not significantly different (P= 0.05) with respect to change in tillage practices.
[b] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 2.2.1.
[c] Number of responses is larger than total respondents in survey. Respondents were able to answer for up to two crop rotations.

Table 2.3. Analysis of survey data highlighting shifts in tillage systems from before to after implementation of a glyphosate-resistant (GR) cropping system, by cropping systems. Individual values represent the current distribution (in percent) among the tillage practices for farms which originated in each of the three tillage system (before implementation of GR crops). Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each crop rotation.

Crop Rotation	Tillage System Before GR Crop	Tillage System After GR Crop: No Till	Reduced Till	Conventional Till	Total	Separated Means[ab]
		------% (number of responses)------				
Continuous GR Cotton	No Till	93(14)	7(1)	0(0)	16(15)	a
	Reduced Till	10(1)	90(9)	0(0)	11(10)	
	Conventional Till	29(19)	33(22)	38(25)	73(66)	
	Total	37(34)	35(32)	28(25)	100(91)	
Continuous GR Soybean	No Till	90(77)	5(4)	5(4)	29(85)	a
	Reduced Till	44(37)	52(43)	4(3)	28(83)	
	Conventional Till	36(47)	24(31)	40(51)	43(129)	
	Total	54(161)	26(78)	20(58)	100(297)	
GR Soybean / Non-GR Crop	No Till	89(81)	9(8)	2(2)	20(91)	b
	Reduced Till	19(37)	78(153)	3(5)	43(195)	
	Conventional Till	17(29)	39(66)	44(73)	37(168)	
	Total	32(147)	50(227)	18(80)	100(454)	
GR Corn / GR Soybean	No Till	94(103)	4(4)	2(2)	29(109)	b
	Reduced Till	23(39)	76(129)	1(1)	44(169)	
	Conventional Till	20(20)	26(27)	54(55)	27(102)	
	Total	43(162)	42(160)	15(58)	100(380)	

(Continued)

Table 2.3. (Continued)

Crop Rotation	Tillage System Before GR Crop	Tillage System After GR Crop			Total	Separated Means[ab]
		No Till	Reduced Till	Conventional Till		
		---% (number of responses)---				
GR Corn / Non-GR Crop	No Till	95(18)	5(1)	0(0)	25(19)	b
	Reduced Till	21(8)	79(31)	0(0)	51(39)	
	Conventional Till	22(4)	22(4)	56(10)	24(18)	
	Total	40(30)	47(36)	13(10)	100(76)	

[a] Crop Rotations sharing the same letter(s) are not significantly different (P= 0.05) with respect to change in tillage practices.
[b] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 2.2.1.

Table 2.4. Analysis of survey data highlighting shifts in tillage systems from before to after implementation of a glyphosate-resistant (GR) cropping system, by state. Individual values represent the current distribution (in percent) among the tillage practices for farms which originated in each of the three tillage system (before implementation of GR crops). Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each state.

State	Tillage System Before GR Crop	Tillage System After GR Crop			Total	Separated Means[ab]
		No Till	Reduced Till	Conventional Till		
		-----% (number of responses)-----				
Illinois	No Till	83(38)	15(7)	2(1)	21(46)	bc
	Reduced Till	22919)	77(68)	1(1)	40(88)	
	Conventional Till	11(9)	21(18)	68(57)	39(84)	
	Total	30(66)	43(93)	27(59)	100(218)	
Indiana	No Till	94(73)	5(4)	1(1)	34(78)	b
	Reduced Till	29(25)	70(61)	1(1)	38(87)	
	Conventional Till	27(18)	27(18)	46(30)	28(66)	
	Total	50(116)	36(83)	14(32)	100(231)	
Iowa	No Till	98(44)	2(1)	0(0)	20(45)	c
	Reduced Till	11(14)	88(108)	1(1)	55(123)	
	Conventional Till	11(6)	35(19)	54(29)	24(54)	
	Total	29(64)	58(128)	13(30)	100(222)	
Mississippi	No Till	68(15)	5(1)	27(6)	11(22)	a
	Reduced Till	25(13)	65(34)	10(5)	27(52)	
	Conventional Till	22(27)	41(49)	37(45)	62(121)	
	Total	28(55)	43(84)	29(56)	100(195)	

(Continued)

Table 2.4. (Continued)

State	Tillage System Before GR Crop	Tillage System After GR Crop			Total	Separated Means[ab]
		No Till	Reduced Till	Conventional Till		
		-----------% (number of responses)-----------				
Nebraska	No Till	97(57)	3(2)	0(0)	26(59)	b
	Reduced Till	31(36)	68(80)	1(1)	52(117)	
	Conventional Till	33(16)	46(22)	21(10)	22(48)	
	Total	49(109)	46(104)	5(11)	100(224)	
North Carolina	No Till	96(66)	4(3)	0(0)	33(69)	a
	Reduced Till	52(15)	48(14)	0(0)	14(29)	
	Conventional Till	39(43)	22(24)	39(43)	53(110)	
	Total	60(124)	20(41)	20(43)	100(208)	

[a] States sharing the same letter(s) are not significantly different (P= 0.05) with respect to change in tillage practices.
[b] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 2.2.1.

Table 2.5. Analysis of survey data highlighting change in tillage system used after adoption of glyphosate resistant (GR) crops as affected by cropping system. Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each farm size.

Farm Size	Tillage System Before GR Crop	Tillage System After GR Crop			Total	Separated Means[ab]
		No Till	Reduced Till	Conventional Till		
		-----% (number of responses)-----				
Small Farms (<220 ha)	No Till	95(53)	2(1)	3(2)	22(56)	a
	Reduced Till	34(25)	65(49)	1(1)	29(75)	
	Conventional Till	30(37)	25(31)	45(56)	49(124)	
	Total	45(115)	32(81)	23(59)	100(225)	
Medium Farms (220-440 ha)	No Till	92(126)	7(10)	1(1)	27(137)	a
	Reduced Till	28(54)	69(132)	3(5)	38(191)	
	Conventional Till	21(37)	38(65)	41(71)	35(173)	
	Total	43(217)	41(207)	16(77)	100(501)	
Large Farms (>440 ha)	No Till	90(114)	6(7)	4(5)	23(126)	b
	Reduced Till	19(43)	80(184)	1(3)	43(230)	
	Conventional Till	24(45)	29(54)	47(87)	34(186)	
	Total	37(202)	45(245)	18(95)	100(542)	

[a] Farm sizes sharing the same letter(s) are not significantly different (P= 0.05) with respect to change in tillage practices.
[b] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 2.2.1.

CHAPTER III

A GROWER SURVEY OF HERBICIDE USE PATTERNS IN GLYPHOSATE RESISTANT CROPPING SYSTEMS

Abstract

A telephone survey was conducted with growers in Iowa, Illinois, Indiana, Nebraska, Mississippi, and North Carolina to discern the utilization of the glyphosate-resistant (GR) trait in crop rotations, weed pressure, tillage practices, herbicide use, and perception of GR weeds. This paper focuses on survey results regarding herbicide decisions made during the 2005 cropping season. Less than 20% of the respondents made fall herbicide applications. The most frequently used herbicides for fall applications were 2,4-D and glyphosate, and these herbicides were also the most frequently used for preplant burndown weed control in the spring. Atrazine and acetochlor were frequently used in rotations containing GR corn. As expected, crop rotations using a GR crop had a high percentage of respondents that made one to three postemergence applications of glyphosate per year. GR corn, GR cotton, and non-GR crops had the highest percentage of growers applying non-glyphosate herbicides during the 2005 growing season. A crop rotation containing GR soybean had the greatest negative impact on non-glyphosate use. Overall, glyphosate use has continued to increase, with concomitant decreases in utilization of other herbicides.

Introduction

The introduction of 2,4-D in the mid-1940's ushered in a new era in which growers had a viable alternative to mechanical control of weeds (Burnside 1996). Over the following decades, there was an explosion of herbicide discovery that changed the way growers managed weeds. During this time of herbicide discovery, several non-selective herbicides were commercialized, including paraquat, glufosinate and glyphosate.

Glyphosate was introduced to the market in the early 1970's for broad spectrum weed control, including perennial weeds. Glyphosate has become one of the world's leading agrochemicals (Woodburn 2000). During the 1970s and early 1980s, research explored means of breeding herbicide resistance into crops (Barrentine et al. 1982). However, it was not until the 1980s that the tools for developing genetically engineered, transgenic crops became available. Several companies saw the advantage of using these technologies to produce transgenic crops that would be resistant to herbicides. Extensive efforts were put forth to develop GR crops, eventually leading to the use of the CP4 gene from *Agrobacterium* sp. This gene codes for a glyphosate-insensitive 5-enol-pyruvylshikimate-3-phosphate synthase (EPSPS) in selected crops (Padgette et al. 1995).

The first commercially available GR crop was soybean, introduced in 1996. GR cotton followed in 1997, and GR corn was introduced in 1998. In 2007, 91% of soybean, 70% of cotton, and 52% of the corn hectarage was planted to GR cultivars in the United States (USDA-NASS 2007). Adoption of GR technologies has been rapid due to a wider spectrum of weeds controlled, less need for tank-mixing other herbicides, and reduced time and labor inputs (Ateh and Harvey 1999; Bradley et al. 2004; Corbett et al. 2004;

Faircloth et al. 2001; Johnson et al. 2000; Reddy and Whiting 2000; Thomas et al. 2004a, 2004b).

After nearly a decade of growing GR crops one would expect significant changes in herbicide use in terms of the frequency and amount of use for herbicide active ingredients. Several researchers have investigated herbicide use patterns following GR crop adoption by examining existing datasets such as the National Agricultural Statistics Service (NASS) chemical use databases and other industry compiled databases (Shaner 2000; Young 2006). An overall reduction in the amount of herbicides applied was noted since grower adoption of GR cropping systems, as was an increased reliance on glyphosate in their weed management programs.

One means of collecting data on actual usage and grower perceptions about weed management is through grower surveys. These surveys have been used in the past to document changes in management practices and grower perceptions about potential problems in a wide range of areas from irrigation practices to perceptions about insect pressure and pesticide use (Dillard 1993; Snyder 1996). Grower surveys have been especially important to weed science and have allowed scientists to gain insight on a number of grower perceptions and practices. Examples include herbicide and herbicide-resistant crop use and grower perceptions of issues such as herbicide resistance in weeds (Charles 1991; Gibson et al. 2005; Gibson et al. 2006; Johnson and Gibson 2006; Llewellyn et al. 2002). By using grower surveys, we have the opportunity to capture a cross-section of weed management practices and their potential problems spanning different states and crop rotations after using a GR crop.

The purpose of this paper is to determine and quantify the effect of GR crop use on growers' herbicide use patterns. The data for this paper are a subset from a dataset generated from a telephone survey that was conducted between November 9, 2005 and

January 6, 2006 to capture many aspects of long-term GR crop use and the changes over time that have occurred because of their use.

Materials and Methods

A survey was designed by the authors and conducted in six states. The telephone survey was conducted by contacting growers from Iowa (IA), Illinois (IL), Indiana (IN), Mississippi (MS), North Carolina (NC), and Nebraska (NE). A list of all growers from these states who had signed an agreement to use the glyphosate-resistant crop [Roundup Ready™] technology was obtained from the 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 management decisions in their farming operations, if they planted a minimum of 101 hectares of corn, soybean, or cotton in 2005, and if they planted one of the traits or trait combinations for a minimum of three years. 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 consisted of four sections dealing with different aspects of their farming practices. The sections dealt specifically with cropping history, weed pressure and tillage practices, herbicide use, and glyphosate-resistant weeds. The respondents were asked to focus their answers on one specific representative field for each cropping system. Complete details of the survey are reported in an introductory paper for this series by Shaw et al. (2009). This paper focused mainly on the herbicide use data generated from the survey.

For this analysis, only the following crop rotations were evaluated: continuous GR corn, continuous GR soybean, continuous GR cotton, GR corn/GR soybean rotation, GR cotton/GR soybean rotation, GR soybean/non-GR crop rotation, and GR corn/non-

GR crop rotation. Grower responses on herbicide application timing and frequency within each cropping system are located in Table 3.1. Table 3.2 lists the most frequently used herbicide active ingredients for fall applications. Table 3.3 lists the herbicide active ingredients used for burndown/preplant applications. Data presented in Table 3.4 are the applications of non-glyphosate herbicide active ingredients pooled across application timings and the percentage of growers in each crop rotation that did not apply a herbicide other than glyphosate during the cropping season in question.

Results and Discussion

The data presented in Table 3.1 are a summary of responses to the questions relating to herbicide use. The data are categorized by crop rotation and herbicide system. The crop rotations examined included continuous GR corn, continuous GR cotton, continuous GR soybean, GR corn/GR soybean, GR cotton/GR soybean, GR soybean/non-GR crop, and GR corn/non-GR crop. The herbicide systems were broken out by: fall applications, burndown/preplant applications, glyphosate in-crop applications, and non-glyphosate in-crop applications. Glyphosate applications were further categorized by number of applications, and non-glyphosate applications were further categorized by timing of the applications. Data from each application timing are discussed below.

Fall Herbicide Use

Between 4 and 16% of growers made fall applications of herbicides prior to planting the specified crop in 2005 (Table 3.1). Four to 6% of the respondents indicated they used a fall herbicide application prior to planting a non-GR crop. Conversely, at least 10% of the growers with crop rotations that included continuous GR corn, continuous GR soybean, and continuous GR cotton used a fall herbicide application. Thus, the use of fall herbicide application may be more common in continuous GR cropping systems. The cause of the increased need for fall herbicide applications in continuous GR cropping systems is beyond the scope of this survey. However, greater reliance on glyphosate and non-residual herbicides has been associated with greater problems with winter annual weeds. The most commonly used herbicides across all crop rotations were glyphosate and 2,4-D (Table 3.2). Atrazine, chlorimuron, and simazine were also frequently used herbicides, but their usage was very specific based on crop tolerances of each rotation. These herbicides are often applied in the fall to control weeds that would otherwise be difficult to manage in the spring and potentially compete with the crop (Wicks et al. 2000).

Preplant Burndown Herbicide Use

Between 20% and 76% of growers used a burndown / preplant application (Table 3.1). Similar to fall herbicide use, the most frequently used herbicides for spring preplant burndown applications across all crop rotations were glyphosate and 2,4-D (Table 3.3). Furthermore, the use of glyphosate was often 4 to 6 times more frequent than 2,4-D, depending on the specific crop rotation. The most frequently used crop-specific herbicides were atrazine and acetochlor in rotations containing corn. In these rotations, glyphosate and 2,4-D were used in preplant burndown applications. A higher percentage of growers in a crop rotation that included GR cotton or GR soybean used glyphosate in their preplant/burndown herbicide applications, particularly the growers in the GR cotton/GR soybean rotation. Glyphosate and glyphosate/2,4-D combinations are effective herbicides for controlling winter annual weeds, and the herbicides' relatively low cost make them attractive options for growers. The usage of glyphosate and 2,4-D was slightly lower for rotations including GR corn, suggesting the utilization of other herbicides. The data in Table 3.3 support this, showing that herbicides such as atrazine and acetochlor were used in rotations that included GR corn. Johnson et al. (2000) also found that by using glyphosate along with reduced rates of chloroacetamide or triazine herbicides provided better control of weed species than full rates of chloroacetamide or triazine herbicides without the addition of glyphosate.

Postemergence Glyphosate Use

Most growers applied two or fewer postemergence applications of glyphosate during crop growth (Table 3.1). However, in crop rotations that include GR cotton, 30 to 40% of the growers made three applications of glyphosate. Prior to GR cotton, preemergence and postemergence-directed herbicide applications or cultivation were used to control weeds in cotton (Culpepper and York 1998; Snipes and Mueller 1992a; 1192b; Wilcut et al. 1995). Since the commercialization of GR cotton, more and more growers have moved toward total postemergence weed control programs. Reasons for this change include the lack of herbicides labeled for preplant or preemergence use, adequate height differential between crops and weeds for postemergence-directed applications is difficult to obtain, marginal crop tolerance to many of these herbicides, and the specialized equipment needed to make these applications (Askew and Wilcut 1999; Culpepper and York 1999; Snipes and Mueller 1992a; 1992b; Wilcut et al. 1997). The main drawback to a total postemergence program using glyphosate is the lack of residual weed control from glyphosate. Multiple applications of glyphosate to the cotton crop are needed to obtain satisfactory weed control if no other weed control tactics are used.

Two or more postemergence applications of glyphosate in GR soybean were used by 66 to 74% of the growers in a continuous GR soybean or GR cotton/GR soybean cropping system (Table 3.1). However, only 47 to 50% of the growers used two or more postemergence applications of glyphosate in a GR corn/GR soybean or GR soybean/non-GR crop rotation. Of the growers in continuous GR soybean production, 62% required at least two postemergence applications of glyphosate (Table 3.1). Of the growers that had GR in their crop rotation, 43 to 53% of them made at least two applications of glyphosate. The tendency to use fewer postemergence applications of glyphosate may be a function of the soybean row spacing, planting date, or geography (soybean maturity length, duration of crop growth). Soybean weed control programs were dominated by imidazolinones and dinitroaniline herbicides from 1992 to 1996, prior to the introduction of GR soybean. With the introduction of GR soybean, many producers began to rely exclusively on glyphosate for weed management (Young 2006). Another reason for the heavy use of glyphosate in GR soybean is that it fills in the gaps left by many conventional soybean weed management programs (Gianessi 2005).

In GR corn, 31 to 44% of the growers used two postemergence applications of glyphosate which is relatively less than the frequency of glyphosate use in GR soybean or GR cotton (Table 3.1). The historical availability of cost-effective non-glyphosate products in corn may partially explain the difference in glyphosate use between crops. For example, atrazine in combination with *s*-metolachlor provides, in most cases, economical, season-long weed control (Thomas et al. 2007). Another reason is the rate of GR corn adoption has been slower than the rate of GR soybean or GR cotton (Johnson and Gibson 2006). The GR trait until recently has not been available in many of the most popular corn hybrids. Glyphosate applications in GR corn can only be made up until the V8 crop stage, or until the crop reaches 30 inches in height (Anonymous

2007). For GR soybean, glyphosate applications can be made up until flowering (R2 stage) (Anonymous 2007). This narrow application window for GR corn may also be a contributing factor to the low adoption of GR corn. Gianessi (2005) found that most corn growers who have adopted GR corn technology have done so because they have difficult-to-control weed problems that necessitate more costly herbicide programs. The work of Johnson et al. (2000) found that the use of glyphosate and atrazine or acetochlor provides better control than the use of glyphosate alone.

Non-Glyphosate Herbicide Use

Growers more frequently utilized a non-glyphosate herbicide prior to planting (12 to 18%) and at planting (16 to 25%) in the production of GR corn (Table 3.1). Corn producers still rely on soil-applied herbicides such as atrazine as the foundation of their weed control programs. Reasons for this are discussed above.

A lower percentage of growers applied non-glyphosate herbicides prior to rotations that included GR soybean or GR cotton (3 to 11%). Common herbicides used prior to planting included diuron, fluometuron, pendimethalin, *S*-metolachlor, and trifluralin. These were commonly used herbicides in weed management programs prior to the development of GR cotton and GR soybean (Young 2006).

During the postemergence timing, rotations that included GR cotton and non-GR crops had 53 to 69% of growers using non-glyphosate herbicides. The herbicides prometryn, pyrithiobac, MSMA, and trifloxysulfuron are still utilized in cotton for over-the-top and layby applications to achieve satisfactory weed control. However only prometryn, pyrithiobac, MSMA, and trifloxysulfuron were commonly used (Table 3.4). The herbicide use pattern may change with the release of new GR cotton cultivars in 2006 that allow for later postemergence applications of glyphosate (Huff et al. 2007).

Prior to the release of the enhanced GR cotton trait, glyphosate applications were limited to the four-leaf stage in cotton. Applications later than this could result in fruit abortion and yield reduction (Viator et al. 2003; 2004). With the introduction of enhanced GR cotton in 2006, glyphosate applications are possible from crop emergence until 7 days prior to harvest (Anonymous 2007).

The non-GR crops in the crop rotations included conventional corn, soybean, and rice. For these crops, traditional postemergence weed management practices, such as those herbicides listed in Table 3.4, were used to achieve acceptable weed control.

During the 2005 growing season 79 and 85% of the producers in GR soybean did not apply a non-glyphosate herbicide (Table 3.1). These results are in agreement with the findings of Shaner (2000), who found a decrease in the use of ALS inhibitors, acetyl CoA carboxylase (AACase) inhibitors and protoporphyrinogen oxidase (PPO) inhibitors in soybean since 1993. Gianessi (2005) found that one glyphosate application in some cases substituted for three to four herbicides, often applied separately, with the potential need for tillage to obtain adequate weed control. Glyphosate-based weed control programs are inexpensive, convenient and, given the market value of soybean over the past couple of years, a very attractive option for producers.

Results from this survey show that in most instances non-glyphosate herbicide based weed management programs have been (GR cotton and GR soybean) or are in the process of being (GR corn) replaced with glyphosate as the core, or sole herbicide. The longer a GR crop is available to producers, and as GR technology develops and advances, these glyphosate-based weed management programs become more attractive to producers. This trend has been especially evident in GR soybean, which has been available for 11 years, and herbicide use patterns have progressively moved toward intensive glyphosate programs. Now that new GR technology for cotton is available, allowing for later applications of glyphosate, one can deduce that this trend will become apparent in GR cotton production as well. The same might be said of GR corn production as the technology matures. Adoption of GR corn in the U.S. has been slower, due again to several factors. Excellent efficacy of existing herbicide programs, as discussed before, may be a contributing factor. Another factor is that GR corn varieties have not been approved for import into Europe (Gianessi 2005). There has been limited information on the efficacy and economics of GR corn (Thomas et al. 2004a), although current research is addressing this deficit (Gianessi 2005; Johnson et al. 2000; Thomas et al. 2004a, 2004b). The increased interest of domestic ethanol production may address export concerns as more corn is used for ethanol production in the U.S.

Researchers have also begun to study the possible adverse effects of weed management systems relying exclusively on glyphosate. Weed shifts and acceleration of glyphosate resistance in weeds are some of the top concerns with these systems (Duke 2005; Shaner 2000; Young 2006). Due to concerns about glyphosate resistance, as well as a number of other management and economic factors, anecdotal data indicate there may be shifts toward greater utilization of soil-applied herbicides. Thus, a follow-up survey will be of great interest to determine why any shifts in herbicide use patterns may continue to occur.

Grower surveys are a valuable tool to document herbicide use patterns and grower attitudes and perceptions driving decisions regarding herbicide selection. The data from this survey will be invaluable reference material for weed scientists and agricultural analysts in understanding the level of glyphosate herbicide usage, the other primary herbicide tools being utilized, and the current benchmarks for herbicide usage in

GR crops. As changes continue to occur in herbicide programs, these data will serve as an important snapshot in time for future reference.

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Table 3.1. Herbicide application summary for all reported crop rotations in Iowa, Illinois, Indiana, Mississippi, North Carolina, and Nebraska for the 2005 growing season. The responses are categorized by application timing.

Crop Rotation	Fall Application of herbicides	Burndown Application prior to or at planting in the spring	Glyphosate Applications				Non-Glyphosate Applications				Avg. No. Yrs. a herbicide other than glyphosate was applied[a]
			1 Application	2 Applications	>3 Applications	Did Not Apply	Prior to Planting	At Planting	Post Emerge	Did Not Apply	
			% of growers making each application								
Continuous GR Corn (n=84)	13	27	54	42	2	1	12	16	24	57	1.3
Continuous GR Soybean (n=307)	14	60	23	62	12	2	4	1	10	85	0.7
Continuous GR Cotton (n=97)	10	76	12	44	42	--	10	10	69	36	2.1
GR Corn/GR Soybean											
GR Corn (n=407)	7	36	63	32	2	3	18	20	13	56	1.2
GR Soybean (n=407)	9	38	48	47	3	2	9	2	6	84	0.9
GR Cotton/GR Soybean											
GR Cotton (n=38)	16	76	18	47	29	--	3	5	58	47	1.6
GR Soybean (n=38)	8	63	26	53	13	3	5	--	16	79	1.1
GR Soybean/Non-GR Crop											
GR Soybean (n=496)	8	42	52	43	4	1	11	2	8	81	1.3
Non-GR Crop (n=496)	6	27	--	--	--	--	22	46	53	23	1.9

(Continued)

Table 3.1. (Continued)

Crop Rotation	Fall Application of herbicides	Burndown Application prior to or at planting in the spring	Glyphosate Applications				Non-Glyphosate Applications				Avg. No. Yrs. a herbicide other than glyphosate was applied[a]
			1 Application	2 Applications	>3 Applications	Did Not Apply	Prior to Planting	At Planting	Post Emerge	Did Not Apply	
	% of growers making each application										
GR Corn/Non-GR Crop											
GR Corn (n=85)	14	25	61	31	2	6	17	25	20	45	1.8
Non-GR Crop (n=85)	4	20	--	--	--	--	12	31	53	33	1.5

[a] Average number of years non-glyphosate herbicide was applied (out of the last 3 years).

Table 3.2. Fall herbicides applied for each crop rotation. Data expressed as percentages of producers in each crop rotation who applied each herbicide.

Crop Rotation	atrazine	simazine	chlorimuron-ethyl	flumioxazin	glyphosate	2,4-D	dicamba	paraquat
	% of growers making each application							
Continuous GR Corn (n=11)	--	--	--	--	36	9	--	--
Continuous GR Soybean (n=43)	--	--	5	--	56	7	5	5
Continuous GR Cotton (n=10)	--	--	--	--	30	--	--	--
GR Corn/GR Soybean								
GR Corn (n=30)	10	17	3	--	16	13	--	--
GR Soybean (n=37)	--	3	27	--	27	19	--	--
GR Cotton/GR Soybean								
GR Cotton (n=0)	--	--	--	--	--	--	--	--
GR Soybean (n=0)	--	--	--	--	--	--	--	--
GR Soybean/Non-GR Crop								
GR Soybean (n=41)	--	2	37	5	32	32	--	--
Non-GR Crop (n=31)	10	26	--	--	10	16	--	--
GR Corn/Non-GR Crop								
GR Corn (n12)	17	--	--	--	25	25	--	--
Non-GR Crop (n=0)	--	--	--	--	--	--	--	--

Table 3.3. Herbicide applied as preplant burndown for each crop rotation. Data expressed as percentages of producers in each crop rotation who applied each herbicide.

Crop Rotation	atrazine	acetochlor	pendimethalin	isoxaflutole	glyphosate	2,4-D	paraquat
	% of growers making each application						
Continuous GR Corn (n=23)	22	17	--	--	52	13	--
Continuous GR Soybean (n=183)	--	--	1	--	76	20	--
Continuous GR Cotton (n=74)	--	--	5	--	90	15	--
GR Corn/GR Soybean							
GR Corn (n=147)	15	13	--	--	40	16	5
GR Soybean (n=155)	--	--	--	--	63	16	2
GR Cotton/GR Soybean							
GR Cotton (n=29)	--	--	--	--	86	--	--
GR Soybean (n=24)	--	--	--	--	92	--	--
GR Soybean/Non-GR Crop							
GR Soybean (n=41)	--	--	--	--	69	20	1
Non-GR Crop (n=31)	8	--	--	5	48	21	8
GR Corn/Non-GR Crop							
GR Corn (n=21)	10	10	--	--	14	24	--
Non-GR Crop (n=17)	--	--	--	--	59	12	--

Table 3.4. Non-glyphosate herbicides applied for each crop rotation. Data expressed as percentages of producers in each crop rotation who applied each herbicide.

Crop rotation	Non-glyphosate herbicides applied
	% of growers making each application
Continuous GR corn (n=36)	47% atrazine, 25% acetochlor, 8% simazine, 6% *S*-metolachlor
Continuous GR soybean (n=46)	26% chlorimuron, 13% flumiclorac, 9% 2,4-D, 2% *S*-metolachlor, 2% pendimethalin, 2% flumioxazin
Continuous GR cotton (n=62)	27% diuron, 19% pyrithiobac, 15% MSMA, 15% trifloxysulfuron, 12% prometryn, 11% pendimethalin, 8% flumioxazin, 8% fluometuron, 8% *S*-metolachlor, 2% 2,4-D
GR corn/GR soybean	
GR corn (n=181)	33% atrazine, 28% acetochlor, 7% *S*-metolachlor, 5% 2,4-D
GR soybean (n=67)	15% pendimethalin, 11% imazethapyr, 9% chlorimuron, 8% *S*-metolachlor, 6% acetochlor, 6% clethodim, 5% 2,4-D , 5% flumioxazin
GR Cotton/GR Soybean	
GR cotton (n=20)	20% MSMA, 20% *S*-metolachlor, 20% trifloxysulfuron, 10% prometryn, 15% flumioxazin, 10% fluometuron
GR soybean (n=0)	--
GR soybean/non-GR crop	
GR soybean (n=94)	15% pendimethalin, 11% 2,4-D, 9% trifluralin, 7% cloransulam, 6% imazethapyr, 5% flumiclorac, 1% acetochlor, 1% nicosulfuron, 1% *S*-metolachlor,
Non-GR crop (n=384)	20% atrazine, 20% *S*-metolachlor, 13% mesotrione, 12% acetochlor, 7% 2,4-D, 7% isoxaflutole, 6% clopyralid, 6% nicosulfuron, 2% pendimethalin, 1% trifluralin, <1% cloransulam
GR corn/non-GR crop	
GR corn (n=47)	32% atrazine, 28% acetochlor, 13% *S*-metolachlor, 4% mesotrione, 2% glufosinate
Non-GR crop (n=57)	16% *S*-metolachlor, 11% 2,4-D, 10% acetochlor, 9% atrazine, 9% mesotrione, 5% glufosinate

CHAPTER IV

DETERMINING GROWER AWARENESS AND EXPERIENCE WITH GLYPHOSATE-RESISTANT WEEDS AND ITS EFFECT ON PREFERENCE TO EDUCATION SOURCES

Abstract

A survey was conducted by phone to nearly 1,200 growers in six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina) in 2005, with the objective of determining awareness of the potential for development of glyphosate resistance, experience with glyphosate-resistant (GR) weeds, and sources of information growers utilized for information on glyphosate resistance. In the survey, growers were asked a series of yes/no questions to determine level of glyphosate resistance awareness and to list sources of information used to learn about glyphosate resistance issues. The majority of the growers (88%) were aware of a weed's potential to develop resistance to glyphosate herbicide, while 44% were aware of state-specific, documented cases of glyphosate weed resistance, and 15% reported having had personal experience with GR weeds. There were no differences among states or cropping systems with respect to awareness of the potential for weeds to develop resistance to glyphosate, or awareness of state-specific cases of documented glyphosate resistance. Twenty-two percent of Indiana growers reported having had personal experience with GR weeds. There were no differences among cropping systems with respect to personal experience with GR weeds. Among sources of information concerning glyphosate resistance issues, farm

publications, dealers/retailers, and university/extension were the most frequent responses (41, 17, and 14%, respectively). Seventeen percent of growers who were and 11% of growers who were not aware of state-specific documented cases of glyphosate resistance listed university/extension as a source of information concerning glyphosate resistance issues as compared to 11% of growers who have had and 15% of growers who have not had personal experience with GR weeds. The majority of growers were aware of the potential for glyphosate resistance, but many lacked information concerning local cases of documented glyphosate resistance in weeds. This information can be used by researchers, extension specialists, and crop advisors to better bridge the information gap between growers and themselves to better disseminate information concerning glyphosate resistance and glyphosate resistance management practices.

Introduction

Over the last decade, the use of GR crop technologies has increased dramatically. In 2005, over 90% of the total U.S. soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum* L.) produced, along with nearly 50% of the corn (*Zea mays* L.) contained a herbicide tolerant gene (Sankula 2006). In 2003, global use of GR soybean reached 60% (James 2005). The introduction of GR crops allowed producers to utilize post-emergence applications of glyphosate as an effective tool for weed management. The use of glyphosate for weed control quickly began to replace preplant tillage and postemergence cultivation, as well as other selective herbicides, as a more economical method of weed control. With the expiration of the glyphosate patent in 2000, the availability of generic glyphosate formulations have made GR cropping systems even more economical (Duke 2005).

The broad-spectrum weed control offered by glyphosate and the economic advantage of applying glyphosate alone versus multiple herbicides targeting different weed species quickly made herbicide programs consisting of glyphosate alone popular in U.S. cropping systems (Givens et al. 2009). We are now at a time where young growers are entering into production agriculture with no knowledge of weed control practices prior to GR crops, which may be a factor in the perpetuation of glyphosate-alone, postemergence weed control programs. With this increased use of glyphosate, it was theorized there would be an increase in the frequency of GR weed biotypes and weed population shifts (Shaner 2000). This has been confirmed, with 16 species worldwide showing resistance to glyphosate (Heap 2010).

In response to the increasing occurrences of resistant weed biotypes, weed scientists began identifying practices to manage the risk of developing GR weed biotypes, including: tank mixes of herbicides with different modes of action (Shaner 2000), inclusion of 2,4-D or dicamba in preplant burndown programs (Loux et al. 2005), use of cultivation (Boerboom and Owen 2006), and educating producers on implementing these practices.

In an effort to quantify the effectiveness of these educational efforts, grower surveys have been employed to measure grower attitudes to various methods of herbicide resistance management strategies (Johnson and Gibson 2006; Lewellyn et al. 2007). Grower surveys have historically been used in agriculture to better understand producers' perceptions on a number of items such as: irrigation practices, insect pressure, pesticide use, herbicide-resistant weeds, and the use of herbicide-resistant crops (Dillard 1993; Snyder 1996). Grower surveys have been especially important to weed science, in that they have allowed scientists to gain insight on a number of grower perceptions and practices. Examples include grower herbicide use and perceptions of items such as herbicide resistance in weeds and herbicide-resistant crop use (Charles 1991; Gibson et al 2005; Gibson et al. 2006; Johnson and Gibson 2006; Llewellyn et al. 2002). Findings from Llewellyn et al. (2002) suggest that though producers have an awareness of herbicide-resistant weeds, they expect new herbicides will be available that will be effective in controlling them. Gibson et al. (2006) and Llewellyn et al. (2007) both found that although a majority of the producers were aware of GR weeds, very few expressed concern. Analysis by Johnson et al. (2009) found that by farm size (large, medium, small), over 75% of all growers were aware of a weed's potential to develop resistance to glyphosate herbicide. Johnson et al. (2009) also found that the highest ranked sources of information concerning glyphosate resistance across the six surveyed states were farm publications, dealers/retailers, and university/extension. Johnson et al. (2009) focused on differences in awareness of glyphosate resistance among farm sizes and states, but they did not explore how grower awareness of GR weeds and their experience with GR weeds might affect their choice for information concerning GR weed issues.

The objective of this paper was to investigate growers' awareness and experience with GR weeds by state and cropping system. It was also of interest to determine the sources growers turn to for information concerning glyphosate resistance issues, and how awareness of glyphosate resistance changes growers' preference of information sources. The data for this paper are a subset from a dataset generated from a telephone survey that was conducted between November 9, 2005 and January 6, 2006 to capture many aspects of long-term GR crop use and the changes over time that have occurred because of their use (Shaw et al. 2009).

Materials and Methods

The telephone survey was conducted by contacting growers from Iowa (IA), Illinois (IL), Indiana (IN), Mississippi (MS), North Carolina (NC), and Nebraska (NE). A list of all growers from these states who had signed an agreement to use the GR crop technology was obtained 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 management decisions in their farming operations, if they planted a minimum of 101 hectares of corn, soybean, or cotton in 2005, and if they planted one of the traits or trait combinations for a minimum of three years. 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 consisted of four sections dealing with different aspects of their farming practices. The sections dealt specifically with cropping history, weed pressure and tillage practices, herbicide use, and GR weeds. The respondents were asked to focus their answers on one specific representative field for each cropping system. Complete details of the survey are reported by Shaw et al. (2009). This paper will focus mainly on the resistance issues data generated from the survey.

The questions used for analysis and discussion in this paper included questions 11a, 12a, 12c, and 13a, and are part of the questionnaire introduced by Shaw et al. (2009). Questions 11a, 12a, and 13a investigated grower awareness of weeds potential to develop resistance to glyphosate herbicide, grower awareness of documented resistance in their state, and grower personal experience with glyphosate resistant weeds respectively. Question 12c probed the growers to list the sources of information they used to learn about weed resistance issues related to glyphosate herbicides. Chi-square analysis on each of the variables of interest was performed using the PROC SURVEYFREQ procedure in SAS[1]. The results of the chi-square analysis for questions 11a, 12a, and 13a are found in Table 4.1. Chi-square analysis of question 11a by state and cropping system are located in Tables 4.2 - 4.3, question 12a by state and cropping system are located in Tables 4.4 - 4.5, and question 13a by state and cropping system are located in Tables 4.6 - 4.7. Chi-Square analysis was also performed on q12c, and the individual results, along with analysis by state and by cropping system are located in Tables 4.9 – 4.11.

Results and Discussion

Awareness to Resistance Potential, State Documented Resistance, and Personal Experience with Resistant Weeds

The first question in the resistance issues section of the survey addressed the growers' awareness to a weeds potential to develop resistance to glyphosate herbicide by asking if a grower is aware of this potential. A "no" answer excluded them from providing an answer to question 11b – 14b. A "yes" answer allowed the grower to progress to question 12a, which asked the grower if they were aware of any specific weeds that had been documented in their state to be resistant to glyphosate herbicide. A "no" answer excluded them from the providing an answer to question 12b – 14b. A "yes" answer allowed the grower to progress to question 13a which asked the grower if they have had any personal experience with weeds resistant to glyphosate herbicide on their farm.

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[1] SAS, Version 9.2, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

Grower awareness of a weed's potential to develop resistance to glyphosate are summarized in Table 4.1. Nearly 90% of growers were aware of a weed's potential to develop resistance to glyphosate herbicide. Forty-four percent of growers were aware of specific weeds in their state with documented resistance to glyphosate herbicide, 15% of growers reported having had personal experience with GR weeds. Similar results were reported by Beckie et al. (2004), in which a survey of 95 growers in Wheatland County, Alberta found that 33% growers suspected, or were aware of, herbicide-resistant weeds on their farm (not specific to GR weed species).

Chi-square analysis of grower awareness of a weed's potential to develop resistance to glyphosate, awareness of state-specific, documented cases of glyphosate resistance, and personal experience with GR weeds by state and by cropping system was also performed to investigate changes in response based on the state and cropping system each grower was associated with (Tables 4.2 – 4.3). There were no differences between states in grower awareness of a weed's potential to develop resistance to glyphosate herbicide (p=0.087). The same was true when analyzed by cropping system (p=0.13). These findings reinforce the results of Johnson et al. (2009), in which greater than 75% of growers across all farm sizes and tillage practices were aware of a weed's potential to develop resistance to glyphosate.

There were no differences between states (p=0.282) with respect to grower awareness of documented cases of glyphosate resistance in their state (Table 4.4). Across all states, the level of awareness ranged from 40% (Illinois) to 49% (Iowa). There were also no differences between cropping systems (p=0.68) with respect to grower awareness of document cases of glyphosate resistance in their state (Table 4.5). Across all cropping systems, the percent of growers aware of state-specific cases of glyphosate resistance ranged from 42% (continuous GR soybean and GR soybean rotated with a non-GR crop) to 62% (GR cotton rotated with GR corn). However, there were differences between states with respect to a grower's personal experience with GR weeds on their farm (Table 4.6). Indiana had the highest percentage of growers (22%) with personal experience with GR weeds, while Iowa, Illinois, and Mississippi had the lowest percentage of growers (12%) reporting having had personal experience with GR weeds. However, cropping systems did not affect grower experience with GR weeds (p=0.822). Across all cropping systems (Table 4.7), the percent of growers who had personal experience with GR weeds ranged from 10% (GR cotton rotated with GR corn) to 20% (GR corn rotated with a non-GR crop). One should remember that this survey was conducted during the winter of 2005-06. Glyphosate resistance in U.S. agriculture was a "new" concept, and not as widely known as it is today.

Grower Sources of Information on Glyphosate Resistance Issues

Sources of information concerning glyphosate resistance issues reported by growers were classified into 9 categories (analysis groupings) to facilitate further analysis. Chi-square analysis of these categories is reported in Table 4.8. The top three sources of information concerning information on glyphosate resistance issues used by growers were farm publications (41%), dealers/retailers (17%), and university/extension (14%).

Illinois had the largest percentage of growers (47%) who used farm publications as a source of information concerning glyphosate resistance, while Iowa had the least, at 36% (Table 4.9). Indiana had 21% of growers reporting dealers/retailers as a source of information concerning glyphosate resistance, while North Carolina had the least, at 12%. The highest occurrence of university/extension as an information source was in Nebraska, at 17%, with the lowest occurrence in Indiana, at 12%. These findings differ slightly from those of Johnson et al. (2009) due to the pooling of categories done in these analyses.

Chi-square analysis indicated significant differences between cropping systems with respect to sources of information concerning glyphosate resistance issues (Table 4.10), and further explore the sources of information on glyphosate resistance first reported by Johnson et al. (2009). The cropping systems with the most responses for farm publications as sources of information included rotation with GR cotton in the crop mix (GR cotton/GR soybean – 47%, continuous GR cotton – 46%, and GR cotton/non-GR crop – 43%). These rotations are predominantly found in the southern U.S., Mississippi in particular. Mississippi was the first of the six states in this survey where horseweed was documented to be resistant to glyphosate (Heap 2010), and information concerning cases of glyphosate resistance flooded the farm publications in this area. With respect to dealers/retailers as a source of information concerning glyphosate resistance, growers in GR corn/GR soybean rotations reported this the most (21%), followed by growers in continuous GR soybean and GR cotton/GR corn rotations (17%), and growers in continuous GR corn, GR cotton/GR soybean, and GR soybean/non-GR crop rotations (16%).

One of the more interesting results was the percentage of responses from cropping systems with respect to university/extension as sources of information concerning glyphosate resistance issues. Continuous GR cotton and GR cotton/non-GR crop systems had approximately double the percentage of responses for university/extension as sources of information as compared to the other cropping systems. These growers may be relying more on information from educational based sources concerning more intensive herbicide programs for dealing with this GR horseweed, more so than growers from other cropping systems that have more convenient options for GR horseweed control where it is a problem. Again, during the time this survey was conducted (winter 2005-06) glyphosate resistance in weeds was an emerging issue. Growers in these affected areas may have started turning to university/extension for recommendations for dealing with glyphosate resistance quicker than their counterparts in other states.

Effect of Resistance Awareness on Grower Sources of Resistance Information

The final sets of results presented differ from those presented by Johnson et al. (2009) by investigating how awareness of documented resistance in each state and personal experience with GR weeds affect grower choices for information on glyphosate resistance issues. Farm publications, dealers/retailers, and university/extension persisted as the top sources of information concerning glyphosate resistance issues for both growers who were and were not aware of documented resistance in their states (Table 4.11). Growers who were aware of documented resistance in their state tended to rely more on other farmers, news media, and university/extension (7, 5, and 17%, respectively), than their unaware counterparts (5, 3, and 11%, respectively). As glyphosate resistance moved from a concept to a reality for growers, they may have turned to sources they deemed “trustworthy” in an effort to learn more about glyphosate resistance.

Table 4.12 contains the Chi-square analysis results of personal experience with GR weeds and grower choices for information on glyphosate resistance issues. Growers were two and eleven times more likely to seek information about glyphosate resistance issues from other farmers and news media than their counterparts who had no personal experience with GR weeds. Two observations of interest were the growers who had personal experience with GR weeds were six times more likely to seek information from chemical companies than their counterparts who had no personal experience with GR weeds, and were less likely to seek information from university/extension than their counterparts (11% versus 15%). These growers may have turned to chemical companies for a solution, or potentially placed the blame on them for glyphosate resistance. Similar survey results were reported by Foreman and Glasgow (2008) from a survey conducted in 2006, Johnson and Gibson (2006) from a survey conducted during the winter of 2003-04, and Llewellyn et al. (2002) from a survey conducted in 2000.

The shift in grower preference for sources of information regarding glyphosate resistance was one of the more interesting findings of this study. There was an increase in the percentage of responses originating from growers with experience with GR weeds who utilized news media as a source of information concerning glyphosate resistance (69 versus 59%). News media included sources such as the internet, radio, and newspapers, suggesting that growers were becoming more proactive in seeking information concerning glyphosate resistance. There also was a sharp decline in the percentage of responses originating from growers with experience with GR weeds versus those aware of documented cases of state-specific cases of glyphosate resistance for the following sources of information: university/extension (40% decline), farm publications (29% decline), and dealer/retailers (18% decline). This, coupled with small increases in the responses for the other sources of information, suggests that growers' preference for sources of information concerning glyphosate resistance grew more diverse as GR weeds began to develop on their farming operations.

Growers relied more upon chemical companies, consultant/agronomists, and meetings after they had experienced GR weeds personally than when they were just aware of state-specific cases of glyphosate resistance. As pointed out earlier, past survey research has noted that growers believe an industry solution is forthcoming concerning glyphosate resistance (Foresman and Glasgow 2008), but new industry solutions, particularly new herbicide chemistries, often take 10 years to bring to market and often exceed $190 million in development and research costs (Fernandez-Cornejo et al. 1998).

This survey has shown that the large majority of responses received from growers were aware of a weeds potential to develop resistance to glyphosate herbicide. These results are in agreement with other surveys done around the world. Llewellyn et al. (2004) in Australia and Beckie et al. (2004) in Canada each found a high level of awareness about herbicide-resistant weeds. Results from this survey also indicate that a significant portion of the responses were from growers who were not aware of state specific cases of documented glyphosate resistance, or have had personal experience with GR weeds (56 and 85%, respectively). This survey was conducted in the winter 2005-06. Glyphosate resistance in weeds was still isolated events. The majority of growers were made aware of the potential for weeds to develop through farm publications and other university/extension outlets (41 and 14%, respectively).

Growers utilized farm publications and dealer/retailers more than educational institutions for information concerning glyphosate resistance issues. However, many of these popular press articles are written by academia. One concern associated with news media is often inconsistent presentation of material in these sources (Johnson et al. 2009). Beckie et al. (2004) and Johnson et al. (2009) both pointed out that academia, industry, and government agricultural institutions must work together to provide a clear and consistent message as to the best management practices associated with preventing and mitigating glyphosate resistance. This will benefit the agricultural community by empowering the grower with a knowledge base to make the right decisions when dealing with glyphosate resistance, which will lead to a greater sustainability of GR cropping systems. Results from this survey should serve as a reminder to academia to routinely evaluate education efforts concerning resistance management, and to be constantly aware of new and creative opportunities to disseminate this knowledge.

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Table 4.1. Summary of yes/no responses to questions 11a, 12a, and 13a.

Question	Yes	No
	------% (number of responses/question)------	
Question 11a (n=1549)		
Are you aware of a weeds potential to develop resistance to glyphosate herbicide?	88(1361)	12(188)
Question 12a (n=1361)		
Are you aware of any specific weeds in your state that have documented to be resistant to glyphosate herbicide?	44(601)	56(760)
Question 13a (n=1487)		
Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?	15(220)	85(1260)

Table 4.2. Chi-square analysis of question 11a, "Are you aware of a weeds potential to develop resistance to glyphosate herbicide?", by state [a].

State	Yes	No
	----------------% (number of responses/state)----------------	
Iowa n=267	88(234)	12(33)
Illinois n=259	92(238)	8(21)
Indiana n=258	89(230)	11(28)
Mississippi n=234	88(206)	12(28)
North Carolina n=270	83(225)	17(45)
Nebraska n=261	87(228)	13(33)

[a] There were no significant differences between states at the 0.05 level of significance.

Table 4.3. Chi-square analysis of question 11a, “Are you aware of a weeds potential to develop resistance to glyphosate herbicide?”, by cropping system [a].

State	Yes	No
	--------% (number of responses/cropping system)--------	
Continuous GR soybean n=307	84(259)	16(48)
Continuous GR corn n=84	88(74)	12(10)
Continuous GR cotton n=97	82(80)	18(17)
GR corn/GR soybean n=407	89(364)	11(43)
GR cotton/GR soybean n=38	90(34)	10(4)
GR cotton/GR corn n=11	73(8)	27(3)
GR soybean/Non-GR crop n=496	89(444)	11(52)
GR corn/Non-GR crop n=85	92(78)	8(7)
GR cotton/Non-GR crop n=24	83(20)	17(4)

[a] There were no significant differences between crop systems at the 0.05 level of significance.

Table 4.4. Chi-square analysis of question 12a, “Are you aware of any specific weeds in your state that have documented to be resistant to glyphosate herbicide?”, by state [a].

State	Yes	No
	----------------% (number of responses/state)----------------	
Iowa n=234	49(115)	51(119)
Illinois n=238	40(94)	60(144)
Indiana n=230	43(98)	57(132)
Mississippi n=206	42(87)	58(119)
North Carolina n=225	44(98)	56(127)
Nebraska n=228	48(109)	52(119)

[a] There were no significant differences between states at the 0.05 level of significance.

Table 4.5. Chi-square analysis of question 12a, “Are you aware of any specific weeds in your state that have documented to be resistant to glyphosate herbicide?”, by cropping system [a].

State	Yes	No
	----------% (number of responses/cropping system)----------	
Continuous GR soybean n=259	42(108)	58(151)
Continuous GR corn n=74	43(32)	57(42)
Continuous GR cotton n=80	50(40)	50(40)
GR corn/GR soybean n=364	46(166)	54(198)
GR cotton/GR soybean n=34	44(15)	56(19)
GR cotton/GR corn n=8	62(5)	38(3)
GR soybean/Non-GR crop n=444	42(186)	58(258)
GR corn/Non-GR crop n=78	49(38)	51(40)
GR cotton/Non-GR crop n=20	55(11)	45(9)

[a] There were no significant differences between cropping systems at the 0.05 level of significance.

Table 4.6. Chi-square analysis of question 13a, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?”, by state.

State		Yes n=227	No n=1260	P[a] (α = 0.05)
Iowa		30[b]	232[b]	
n=262	% within state	12	88	
	% within yes/no	13	18	
Illinois		30[b]	220[b]	
n=250	% within state	12	88	
	% within yes/no	13	18	
Indiana		56[b]	197[b]	
n=253	% within state	22	78	
	% within yes/no	25	16	0.003
Mississippi		26[b]	199[b]	
n=225	% within state	12	88	
	% within yes/no	12	16	
North Carolina		44[b]	205[b]	
n=249	% within state	18	82	
	% within yes/no	19	16	
Nebraska		41[b]	207[b]	
n=248	% within state	17	83	
	% within yes/no	18	16	

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Frequencies reported for each response.

Table 4.7. Chi-square analysis of question 13a, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?”, by cropping system [a].

State	Yes	No
	----------% (number of responses/cropping system)----------	
Continuous GR soybean n=294	14(41)	86(253)
Continuous GR corn n=82	16(13)	84(69)
Continuous GR cotton n=85	11(9)	89(76)
GR corn/GR soybean n=392	17(65)	83(327)
GR cotton/GR soybean n=35	11(4)	87(31)
GR cotton/GR corn n=10	10(1)	90(9)
GR soybean/Non-GR crop n=486	15(72)	85(412)
GR corn/Non-GR crop n=82	20(16)	80(66)
GR cotton/Non-GR crop n=21	19(4)	81(17)

[a] There were no significant differences between cropping systems at the 0.05 level of significance.

Table 4.8. Chi-square analysis of responses to question 12c, “From what sources have you learned about weed resistance issues related to glyphosate herbicides?”.

Sources of Information	Responses n=1947	P[a] (α = 0.05)
	---% (number of responses/question)---	
Dealers/retailers	17(324)	
Farm publications	41(796)	
Other farmers	6(118)	
Experience	2(35)	
News media	4(81)	<0.0001
Meetings	1(26)	
University / extension	14(270)	
Chemical companies	2(49)	
Consultant / agronomist	1(18)	
I don’t know	12(230)	

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).

Table 4.9. Chi-square analysis of responses to question 12c, “From what sources have you learned about weed resistance issues related to glyphosate herbicides?”, by state.

Responses		State[a] IA n=367	IL n=323	IN n=327	MS n=289	NC n=300	NE n=341	P[b] (α = 0.05)
Dealers/retailers		69[c]	47[c]	68[c]	55[c]	34[c]	51[c]	
n=324	% within response	21	14	21	17	11	16	
	% within state	19	14	21	19	12	15	
Farm publications		133[c]	151[c]	140[c]	117[c]	124[c]	131[c]	
n=796	% within response	17	19	18	15	15	16	
	% within state	36	47	43	40	41	39	
Other farmers		30[c]	20[c]	11[c]	12[c]	25[c]	20[c]	
n=118	% within response	26	17	9	10	21	17	0.040
	% within state	8	6	3	4	8	6	
Experience		6[c]	2[c]	6[c]	5[c]	7[c]	9[c]	
n=35	% within response	17	6	17	14	20	26	
	% within state	2	1	2	2	2	3	
News media		11[c]	15[c]	10[c]	12[c]	14[c]	19[c]	
n=230	% within response	14	18	12	15	17	24	
	% within state	3	5	3	4	5	6	

(Continued)

Table 4.9. (Continued)

Responses		State[a] IA n=367	IL n=323	IN n=327	MS n=289	NC n=300	NE n=341	P[b] (α = 0.05)
Meetings		4[c]	6[c]	6[c]	5[c]	3[c]	2[c]	
n=26	% within response	15	23	23	19	12	8	
	% within state	1	5	2	2	1	1	
University / extension		47[c]	42[c]	38[c]	41[c]	45[c]	67[c]	
n=270	% within response	17	16	14	15	17	21	
	% within state	13	13	12	14	15	17	
Chemical companies		11[c]	6[c]	7[c]	6[c]	11[c]	8[c]	0.040
n=49	% within response	23	12	14	12	23	16	
	% within state	3	2	2	2	4	2	
Consultant / agronomist		7[c]	0[c]	0[c]	2[c]	6[c]	3[c]	
n=18	% within response	39	0	0	11	33	17	
	% within state	2	0	0	1	2	1	
I don't know		49[c]	34[c]	41[c]	34[c]	31[c]	41[c]	
n=230	% within response	21	15	18	15	13	18	
	% within state	13	10	12	12	10	12	

[a] IA, Iowa; IL, Illinois; IN, Indiana; MS, Mississippi; NC, North Carolina; NE, Nebraska
[b] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[c] Frequencies reported for each response.

Table 4.10. Chi-square analysis of responses to question 12c, “From what sources have you learned about weed resistance issues related to glyphosate herbicides?”, by cropping system.

Responses		Cont. GR Soybean n=384	Cont. GR Corn n=107	Cont. GR Cotton n=112	GR Corn/GR Soybean n=489	GR Cotton/GR Soybean n=43
Dealers/retailers		66^{b}	17^{b}	13^{b}	104^{b}	7^{b}
n=324	% within response	21	5	4	32	2
	% within rotation	17	16	11	21	16
Farm publications		151^{b}	44^{b}	52^{b}	192^{b}	20^{b}
n=796	% within response	19	5	6	24	3
	% within rotation	39	41	46	39	47
Other farmers		30^{b}	4^{b}	5^{b}	18^{b}	3^{b}
n=118	% within response	26	3	4	15	3
	% within rotation	8	4	5	4	7
Experience		11^{b}	2^{b}	1^{b}	5^{b}	1^{b}
n=35	% within response	31	6	3	14	3
	% within rotation	3	2	1	1	2
News media		9^{b}	9^{b}	3^{b}	21^{b}	0^{b}
n=81	% within response	11	11	4	26	0
	% within rotation	2	8	3	4	0

(Continued)

Table 4.10. (Continued)

Responses		GR Cotton/GR Corn n=12	GR Soybean/Non-GR Crop n=646	GR Corn/Non-GR Crop n=117	GR Cotton/Non-GR Crop n=28	P[a] (α = 0.05)
Dealers/retailers		2[b]	105[b]	10[b]	0[b]	
n=324	% within response	1	32	3	0	
	% within rotation	17	16	8	0	
Farm publications		4[b]	279[b]	42[b]	12[b]	
n=796	% within response	1	35	5	2	
	% within rotation	34	43	36	43	
Other farmers		1[b]	38[b]	18[b]	1[b]	
n=118	% within response	1	32	15	1	<0.0001
	% within rotation	8	6	15	3	
Experience		0[b]	13[b]	2[b]	0[b]	
n=35	% within response	0	37	6	0	
	% within rotation	0	2	2	0	
News media		0[b]	30[b]	7[b]	2[b]	
n=81	% within response	0	37	9	2	
	% within rotation	0	5	6	7	

(Continued)

Table 4.10. (Continued)

Responses		Cont. GR Soybean n=384	Cont. GR Corn n=107	Cont. GR Cotton n=112	GR Corn/GR Soybean n=489	GR Cotton/GR Soybean n=43
Meetings		4[b]	0[b]	2[b]	5[b]	0[b]
n=26	% within response	15	0	8	19	0
	% within rotation	1	0	2	1	0
University / extension		52[b]	10[b]	27[b]	64[b]	7[b]
n=270	% within response	19	4	10	24	3
	% within rotation	14	9	24	13	16
Chemical companies		8[b]	3[b]	1[b]	21[b]	0[b]
n=49	% within response	16	6	2	43	0
	% within rotation	2	3	1	4	0
Consultant / agronomist		3[b]	3[b]	0[b]	7[b]	0[b]
n=18	% within response	17	16	0	39	0
	% within rotation	1	3	0	1	0
I don't know		50[b]	15[b]	8[b]	61[b]	5[b]
n=230	% within response	22	6	4	27	2
	% within rotation	13	14	7	12	11

(Continued)

Table 4.10. (Continued)

Responses		GR Cotton/GR Corn	GR Soybean/Non-GR Crop	GR Corn/Non-GR Crop	GR Cotton/Non-GR Crop	P[a]
		n=12	n=646	n=117	n=28	(α = 0.05)
Meetings		0[b]	12[b]	2[b]	1[b]	
n=26	% within response	0	46	8	4	
	% within rotation	0	2	2	4	
University / extension		1[b]	85[b]	15[b]	9[b]	
n=270	% within response	0	31	6	3	
	% within rotation	8	13	13	32	
Chemical companies		1[b]	10[b]	4[b]	1[b]	<0.0001
n=49	% within response	2	21	8	2	
	% within rotation	8	2	3	4	
Consultant / agronomist		0[b]	2[b]	3[b]	0[b]	
n=18	% within response	0	11	17	0	
	% within rotation	0	0	3	0	
I don't know		3[b]	72[b]	14[b]	2[b]	
n=230	% within response	1	31	6	1	
	% within rotation	25	11	12	7	

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Frequencies reported for each response.

Table 4.11. Chi-square analysis of responses to question 12c, “From what sources have you learned about weed resistance issues related to glyphosate herbicides?”, by awareness of documented weed resistant to glyphosate herbicide in each state.

Responses		Awareness Yes n=1014	Awareness No n=933	P[a] (α = 0.05)
Dealers/retailers		162[b]	162[b]	
n=324	% within response	50	50	
	% within yes/no	16	17	
Farm publications		363[b]	433[b]	
n=796	% within response	46	54	
	% within yes/no	36	41	
Other farmers		72[b]	46[b]	
n=118	% within response	61	39	
	% within yes/no	7	5	
Experience		26[b]	9[b]	
n=35	% within response	74	26	
	% within yes/no	3	1	
News Media		48[b]	33[b]	
n=81	% within response	59	41	
	% within yes/no	5	3	
Meetings		20[b]	6[b]	<0.0001
n=26	% within response	77	23	
	% within yes/no	2	7	
University / extension		172[b]	98[b]	
n=270	% within response	64	36	
	% within yes/no	17	11	
Chemical companies		35[b]	14[b]	
n=49	% within response	71	29	
	% within yes/no	3	2	
Consultant / agronomist		15[b]	3[b]	
n=18	% within response	83	17	
	% within yes/no	1	1	
I don’t know		101[b]	129[b]	
n=230	% within response	44	56	
	% within yes/no	10	12	

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Frequencies reported for each response.

Table 4.12. Chi-square analysis of responses to question 12c, "From what sources have you learned about weed resistance issues related to glyphosate herbicides?", by personal experience with weeds resistant to glyphosate herbicide.

Responses		Awareness Yes n=620	No n=1330	P[a] (α = 0.05)
Dealers/retailers		103[b]	221[b]	
n=324	% within response	32	68	
	% within yes/no	17	17	
Farm publications		137[b]	673[b]	
n=810	% within response	17	83	
	% within yes/no	22	50	
Other farmers		52[b]	53[b]	
n=105	% within response	50	50	
	% within yes/no	8	4	
Experience		28[b]	7[b]	
n=35	% within response	80	20	
	% within yes/no	4	1	
News media		71[b]	12[b]	
n=83	% within response	86	15	
	% within yes/no	11	1	
Meetings		18[b]	8[b]	<0.0001
n=26	% within response	69	31	
	% within yes/no	3	1	
University / extension		65[b]	205[b]	
n=270	% within response	24	76	
	% within yes/no	11	15	
Chemical companies		35[b]	14[b]	
n=49	% within response	71	29	
	% within yes/no	6	1	
Consultant / agronomist		16[b]	2[b]	
n=18	% within response	89	11	
	% within yes/no	3	0	
I don't know		95[b]	135[b]	
n=230	% within response	41	59	
	% within yes/no	15	10	

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Frequencies reported for each response.

CHAPTER V

EFFECT OF GROWER AWARENESS AND EXPERIENCE WITH GLYPHOSATE-RESISTANT WEEDS ON PERCEIVED EFFECTIVENESS OF GLYPHOSATE RESISTANCE MANAGEMENT PRACTICES

Abstract

A survey was conducted by phone to nearly 1,200 growers in six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina) in 2005, with the objective of determining awareness of the potential for development of glyphosate resistance, attitudes towards resistance management, and experience with glyphosate-resistant (GR) weeds. In the survey, growers were asked to rank the effectiveness of seven practices aimed at minimizing the development of glyphosate resistance in weeds. On a 1-10 scale of effectiveness, growers ranked tillage the lowest (5.5) and using the correct label rates of herbicides at the proper timing for the size and type of weeds present highest (8.6). Growers in Mississippi ranked the practices slightly more effective. Growers that have had personal experience with GR weeds were more knowledgeable about practices that could be used to mitigate them. With respect to obstacles to adopting the practices aimed at minimizing the development of glyphosate resistance in weeds, the most frequent responses were “nothing”, “cost”, and “weed control”. Cost was the biggest obstacle for rotating herbicide chemistries from one year to the next, tillage, rotating crops, using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide, and using more than one herbicide chemistry in a

given year such as glyphosate and another post-applied herbicide. The biggest obstacle for using the correct label rates of herbicides at the proper timing for the size and type of weeds present was weather. The biggest obstacle to rotating away from a Roundup Ready crop to a non-Roundup Ready crop was poor weed control. Growers may have an unrealistic perception of the costs of each of these practices, particularly in light of the cost of not preventing the development of GR weeds. Using this information, researchers, extension, and crop advisors can better target education efforts aimed at conveying the correct information about glyphosate resistance management and preventative practices.

Introduction

Over the last decade, the use of GR crop technologies has increased dramatically. In 2005, over 90% of the total U.S. soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum* L.) crops produced, along with nearly 50% of the corn (*Zea mays* L.) contained a herbicide tolerant gene (Sankula 2006). In 2003, global use of GR soybean reached 60% (James 2005). The introduction of GR crops allowed producers to apply glyphosate after crop emergence as an effective tool for weed management. The use of glyphosate for weed control quickly began to replace preplant tillage and postemergence cultivation, as well as other selective herbicides, as a more economical method of weed control. With the expiration of the glyphosate patent in 2000, the availability of generic glyphosate formulations has made GR cropping systems even more economical (Duke 2005).

To date, there have been sixteen weed species documented with resistance to glyphosate worldwide including, rigid ryegrass (*Lolium rigidum* Gaudin), 1996; goosegrass [*Eleusine indica* (L.) Gaertn.], 1997; horseweed [*Conyza canadensis* (L.)

Cronq.], 2000; Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot], 2001; hairy fleabane [*Conyza bonariensis* (L.) Cronq.], 2003; buckhorn plantain (*Plantago lanceolata* L.), 2003; common ragweed (*Ambrosia artemisiifolia* L.), 2004; giant ragweed (*Ambrosia trifida* L.), 2004; ragweed parthenium (*Parthenium hysterophorus* L.), 2004; Palmer amaranth (*Amaranthus palmeri* S. Wats.), 2005; common waterhemp (*Amaranthus rudis* Sauer), 2005; johnsongrass [*Sorghum halepense* (L.) Pers.], 2005; sourgrass [*Digitaria insularis* (L.) Mez ex Ekman], 2006; and junglerice [*Echinochloa colona* (L.) Link], 2007 (Heap 2005). In response to the increasing occurrences of GR weed biotypes, weed scientists began identifying practices to manage the risk of developing glyphosate resistance including: tank mixes of preplant herbicides with different modes of action (Shaner 2000), inclusion of 2,4-D or dicamba in burndown programs (Loux et al. 2005), and use of tillage or cultivation (Boerboom and Owen 2006). Strong educational programs are underway to encourage implementation of these practices.

Awareness of resistance issues does not always translate into the appropriate actions. Llewellyn et al. (2002) found that growers in Western Australia had a relatively high level of awareness about herbicide-resistant weeds. As noted in the previous chapter, 88% of the growers surveyed were aware of the potential to develop resistance to glyphosate resistance. In a survey of consumers, Roberts (2004) found a high rate of awareness concerning biotechnology, but little to no accurate knowledge concerning biotechnology. Personal experiences often influence a person’s perception of an event or risk (Peacock et al. 2004), and that perceived risk may vary based on the proximity of a person to risk. Perceived hurricane risk increased with homeowner locations in higher wind zone areas. In other words, if a homeowner was located in an area that would sustain higher hurricane force winds, their perception of risk was greater than those homeowners located in areas of lower sustained hurricane force winds. Personal experience may have more of an effect on heightening individual perception (Lindell and Perry 2000). In much the same way, growers may not feel the need to gain knowledge on a subject unless it has the potential to influence them personally.

The objectives of this research were to investigate how grower awareness of GR weeds affects their attitudes and perceptions toward practices aimed at minimizing the development of GR weeds. Grower-stated obstacles to implementing these practices will be compared and contrasted, depending on their state of awareness about GR weeds. The data for this paper are a subset from a dataset generated from a telephone survey that was conducted between November 9, 2005 and January 6, 2006 to capture many aspects of long-term GR crop use and the changes over time that have occurred because of their use (Shaw et al. 2009).

Materials and Methods

A telephone survey was conducted by contacting growers from Iowa (IA), Illinois (IL), Indiana (IN), Mississippi (MS), North Carolina (NC), and Nebraska (NE). A list of all growers from these states who had signed an agreement to use the GR crop [Roundup Ready™] technology was obtained from the 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 management decisions in their farming operations, if they planted a minimum of 101 hectares of corn, soybean, or cotton in 2005, and if they planted one of the traits or trait combinations for a minimum of three years. 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 consisted of four sections dealing with different aspects of their farming practices. The sections dealt specifically with cropping history, weed pressure and tillage practices, herbicide use, and GR weeds. The respondents were asked to focus their answers on one specific representative field for each cropping system. Complete details of the survey are reported by Shaw et al. (2009). This paper will focus mainly on section four of the survey: the questions dealing with effectiveness of certain practices to preventing the development of glyphosate resistance in weeds, and the obstacles to adopting these practices.

Questions used for analysis and discussion in this paper included questions 11a, 12a, 13a, 14a, 15, and 16 from Shaw et al. (2009). Questions 11a, 12a, 13a, and 14a investigated grower awareness of the potential to develop resistance to glyphosate herbicide, grower awareness of documented resistance in their state, grower personal experience with GR weeds, and grower adoption of practices to prevent development of glyphosate resistance in weeds, respectively. Question 15 probed for the effectiveness of certain practices in preventing the development of glyphosate resistance in weeds, and Question 16 probed for obstacles to preventing the adoption of the practices listed in Question 15. An explanation of the variables and questions used in the analysis for this paper are found in Table 5.1.

Analysis of variance was used to determine significant differences in effectiveness among practices (Table 5.2), and means were separated using Tukey's test in SAS[1]. Means were separated by practice and state (Tables 5.3-5.4), and by each significant factor in each practice (Tables 5.5-5.6).

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[1] SAS, Version 9.2, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

The second set of analyses focused on the obstacles to adopting practices that may prevent development of glyphosate resistance in weeds. Chi-square analysis on each of the variables of interest was performed using SAS. Results from these analyses are presented in Tables 5.7 – 5.11.

Results and Discussion

Effectiveness of Practices at Preventing Development of Glyphosate Resistance in Weeds

The first objective was to investigate how grower awareness to resistance would impact their perception on the effectiveness of practices to preventing the development of glyphosate resistance in weeds. A list of the seven practices that growers were asked to evaluate is listed in Table 5.1. Table 5.2 summarizes the initial results from the analysis of variance for the first objective.

There were substantial differences between practices with respect to rated effectiveness of minimizing the development of glyphosate resistance in weeds (Table 5.2). Using the correct label rates of herbicide at the proper timing for the size and type of weeds present and rotating crops were rated the highest with respect to how growers rated the effectiveness of the practices at preventing the development of glyphosate resistance (Table 5.3). Tillage and rotating away from a GR crop to a non-GR crop were rated the lowest. At the time of this survey in 2005, glyphosate resistance management strategies were in their infancy. According to the Roundup WeatherMAX supplement label (Anonymous 2005) for management of GR horseweed, there was no mention of residual herbicides or addition of postemergence, foliar-applied herbicides to be used in conjunction with the labeled rate of Roundup WeatherMAX™ for the control of GR horseweed in cotton or soybean.

There were a few differences between states with respect to mean rated effectiveness of practices aimed at minimizing the development of glyphosate resistance in weeds (Table 5.2). Mississippi growers rated the practices higher with respect to their effectiveness in preventing the development of glyphosate resistance in weeds than Indiana, Illinois, and Nebraska growers (Table 5.4). Although there were differences between states (MSD = 0.28), there appeared to be no practical difference with respect to the numerical range of the average ratings of effectiveness (6.9-7.3). Results showed that the growers in all surveyed states appeared to have similar attitudes toward practices aimed at preventing the development of glyphosate resistance in weeds.

Table 5.5 examines the differences in grower awareness with respect to rating the effectiveness of the practices at preventing the development of glyphosate resistance. There were differences between growers who were or were not aware of GR weeds in their state, and growers who were or were not using a practice to minimize the development of glyphosate resistance with respect to how they rated the practice's effectiveness at preventing glyphosate resistance in weeds. There were no differences among growers who were and were not aware of a weed's potential to develop resistance to glyphosate, and growers who have and have not had personal experience with GR weeds with respect to rated effectiveness of the practices at preventing the development of glyphosate resistance. The segment of growers who were aware of a weed's potential to develop resistance to glyphosate may have felt GR weeds were not going to be a problem. It is important to remember that widespread GR populations of weeds, with the exception of horseweed in the southern U.S., were not the norm in the major agronomic crops of North America at that time (Heap 2005). During the period of time in which this survey was taken, a grower who experienced a resistant weed may not have been actively employing a practice to prevent the development of GR weeds. Only if a farmer had been employing one of the practices did they perceive the effectiveness of that practice greater than those who were not employing one of the practices to minimize the potential for developing GR weeds.

Table 5.6 summarizes the results of the post hoc tests for each resistance management practice. Across all practices, with the exception of tillage, there was a difference between growers who had implemented a practice to prevent the development of glyphosate resistance and those who had not implemented a practice to prevent the development of glyphosate resistance with respect to how the growers rated each practice's effectiveness at preventing the development of glyphosate resistance in weeds (Table 5.2). This may be in part because growers who were using these practices had first-hand knowledge of their potential effectiveness, thus rating them higher than the growers who were not implementing any of the practices. There were differences in the effectiveness of using glyphosate in combination with a residual or other post-applied herbicide between growers who were and were not aware of specific GR weeds in their state.

Only the practice "tillage" had no differences between growers with respect to rated effectiveness at preventing the development of glyphosate resistance in weeds (Table 5.2). One possible explanation for this is that reduced-tillage cropping systems were seen as a benefit to the adoption of GR cropping systems, as reported in the survey results by Givens et al. (2009). Tillage may not have been considered a practice that could effectively minimize the development of glyphosate resistance in weeds. Johnson and Gibson (2006) found similar results from a survey; 1% of the growers felt changes in tillage practices contributed to the development of GR weeds. Thus to growers, if changes in tillage did not contribute to the development of glyphosate resistance, changes in tillage may not be an effective practice at minimizing the development of glyphosate resistance.

Obstacles to Adopting Practices to Reduce the Risk of Developing Glyphosate Resistance in Weeds

The second set of analyses performed investigated the obstacles perceived by the growers to adopting each of the seven practices aimed at minimizing the development of glyphosate resistance in weeds. In total, there were 44 obstacles given among the practices. To facilitate analysis, only obstacles with a frequency greater than five were used, and the remaining obstacles were consolidated into like groups. Table 5.1 lists the new obstacle groups (obstacles 1-7) and the corresponding obstacles consolidated in each group.

Seven Chi-square tests were performed, consisting of the following: differences among obstacles across all practices, differences among obstacles between practices, differences among obstacles between states, differences among obstacles between the “yes” and “no” responses to awareness of weeds potential to develop resistance to glyphosate herbicide, differences among obstacles between the “yes” and “no” responses to awareness of state-specific, documented weed resistance to glyphosate herbicide, differences among obstacles between the “yes” and “no” responses to personal experience with GR weeds, and differences among obstacles between the “yes” and “no” responses to adoption of practices targeted at reducing the risk of developing glyphosate resistance in weeds. Analyses results are located in Table 5.7. The analyses indicated differences among: obstacles across all practices (p-value = 0.018), between practices (p-value = <0.0001), obstacles between the “yes” and “no” responses to awareness of state-specific, documented weed resistance to glyphosate herbicide (p-value = 0.002), and obstacles between the “yes” and “no” responses to personal experience with GR weeds (p-value = <0.0001). These analyses are explored further in Tables 5.8 - 5.11.

Among the obstacles listed for each of the practices, 67% of growers responded that there were no obstacles to adopting the seven practices (Table 5.8). The second, third, and fourth most frequently cited obstacles were “cost,” “weed control,” and “weather” (14, 8, and 6%, respectively). An important item to note is the sharp rise in fuel prices that began in 2005 (Dept. of Energy 2009). Farmers were faced with having to reduce fuel costs, and many of the practices suggested in the survey implied additional trips across the field. This, coupled with the addition of alternative and potentially expensive herbicides required for some of the other practices, may have contributed to “cost” being one of the major obstacles to adopting practices aimed at minimizing the development of glyphosate resistance in weeds.

Table 5.9 explores the distribution of obstacles by practice in more detail by showing the distribution of each obstacle among practices and the distribution of each obstacle within each practice. The greatest occurrence of the obstacle “weather” was with the practice of using the correct labeled rate of glyphosate at the proper timing (75%). This is understandable, since weather may be the biggest impediment to applying herbicides at the correct timing for the target weed species. The greatest occurrence of the obstacle “cost” was within the practices of using glyphosate in combination with a residual or other post-applied herbicide, using more than one herbicide chemistry with glyphosate such as a residual, and using more than one herbicide chemistry with glyphosate such as another post-applied herbicide. This comes as no surprise as well, since this would entail additional herbicide purchases. What is of interest is that the obstacle "cost" did not have as great an occurrence in the practice of rotating away from GR crops to a non-GR crop, with the potential added cost of herbicide applications associated with this rotation. As expected, the greatest occurrence of the obstacle "soil loss/soil erosion" was within the practice of tillage (85%). The obstacle "weed control/application timing" had the largest occurrence in the practices using the correct label rates of herbicide at the proper timing for the size and type of weeds present and rotating away from a GR crop to a non-GR crop. It is understandable that growers may perceive less weed control when they are not able to use a non-selective herbicide over the top of their crops. What is interesting is that growers perceived weed control/application timing as an obstacle to using the correct label rates of herbicide at the proper timing for the size and type of weeds present. A possible explanation is that there may not be a single optimum application window for the application of glyphosate due to differing weed species present at various growth stages in the field. The single greatest occurrence of the obstacle "time consuming/inconvenience" was with the practice of rotating away from a GR crop to a non-GR crop. It is understandable why growers would perceive this as an obstacle, given the potential for complex herbicide choices for weed control and the additional applications for these herbicides. Not surprisingly, the obstacle "nothing", had the highest occurrence in the practice using the correct label rates of herbicide at the proper timing for the size and type of weeds present, while the distribution of responses for the obstacle "I don't know" was fairly evenly distributed between the practices of rotating crops, using the labeled rate of glyphosate and the proper timing, using glyphosate in combination with another post-applied herbicide, and rotating away from a GR crop to a non-GR crop.

The results of the distribution of obstacles among the yes/no responses to awareness of state-specific, documented weed resistance to glyphosate herbicide are summarized in Table 5.10. Growers who were aware of state-specific, documented cases of GR weeds tended to list more obstacles to each of the practices aimed at reducing the risk of developing GR weeds than their counterparts who were not. The obstacles containing the biggest discrepancies were obstacles "soil loss/erosion", "I don't know", "weed control", and "weather", with a percent difference of occurrence between groups of 38, 34, 28, and 18%, respectively. These discrepancies suggest a proximal response to the knowledge of the threat of GR weeds.

Along with the previously mentioned research by Peacock et al. (2005) dealing with hazard proximity and perceived risk, research by Petty and Cacioppo (1981) in peripheral-based perceptions may also explain the disparity between the growers who were aware of state-documented cases of glyphosate resistance in weeds and those who were not aware. Even though growers may have been proximally closer to GR weeds, lack of personal experience with GR weeds may have still fueled a peripherally-based perception of the problem. Growers' sources of information concerning GR weeds, as reported earlier, mostly originate from farm publications. Slovic (1997) demonstrated that difficulties understanding problems and mitigation practices, biased media, misleading personal experiences, and irrational fears often led to misjudged risks and inappropriate responses. These factors may have contributed to exaggerated perceptions of obstacles within growers who were aware of state-documented cases of glyphosate weed resistance.

The effects of personal experience with a situation and its effect on individual perception, as documented by Lindell and Perry (2000), can be seen in Table 5.11. The majority of the obstacles reported were by growers who had not yet encountered GR weeds on their farming operations. This is in stark contrast from the results presented in Table 5.10 which contrast obstacle perception between growers who were or were not aware of state-documented cases of glyphosate weed resistance. The obstacles in which this was most prominent were the obstacles “cost”, “weather”, and “weed control” with 70, 65, and 61% of the occurrence of these obstacles originating from growers who had no personal experience with GR weeds. Hamstra (1995) saw similar results when studying potential benefits versus perceived risks of genetically-modified foods. In consumers, the potential benefits of genetically modified foods outweighed the perceived risks. In much the same, the potential loss attributed to not minimizing the development of glyphosate resistance in weeds may have far outweighed the cost for adopting practices aimed at minimizing the development glyphosate resistance in weeds for growers with personal experience with GR weeds. Lynne et al. (1988) found that attitudes about conservation influenced the adoption of soil conservation practices. In this same way, attitudes toward management practices may have changed once a grower has had personal experience with a GR weed.

Glyphosate resistance has become an increasing problem, particularly with the documented resistance of *Amaranthus* spp. (Culpepper et al 2006; Owen and Zelaya 2005). To compound the problem, past grower surveys have shown that the majority of growers believe that industry will provide a new herbicide or other technical solution to combat glyphosate resistance (Foresman and Glasgow 2008; Llewellyn et al. 2002). Weed scientists must provide a clear and consistent message concerning mitigation and prevention of GR weeds, as inconsistent information may diminish the impact of the information (Johnson 1993; Perry et al. 1982). The data presented in this paper clearly indicate the need for continued efforts and new methods to educate growers about the importance of minimizing the development glyphosate resistance and managing existing populations of GR weeds.

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Table 5.1. Variable names and corresponding survey questions used in data analysis.

Variable	Survey Question
Q11a	Are you aware of the potential for weeds to develop resistant to glyphosate herbicides? (YES or NO)
Q12a	Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide? (YES or NO)
Q13a	Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides? (YES or NO)
Q14a	Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm? (YES or NO)
Practice	**Practices to manage potential resistance to glyphosate**
Practice 1	Rotating herbicide chemistries from one year to the next
Practice 2	Tillage
Practice 3	Rotating crops
Practice 4	Using the correct label rates of herbicide at the proper timing for the size and type of weeds present
Practice 5	Using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide
Practice 6	Using more than one herbicide chemistry in a given year such as glyphosate and another post-applied herbicide
Practice 7	Rotating away from a Roundup Ready crop to a non-Roundup Ready crop
Obstacles	**Obstacles to implementing a practices to manage potential resistance to glyphosate**
Obstacle 1	Weather

(Continued)

Table 5.1. (Continued)

Obstacles	Obstacles to implementing a practices to manage potential resistance to glyphosate
Obstacle 2	Fuel Prices/Cost/Economics/Labor Intensive/Labor Costs/Market Price
Obstacle 3	Soil Erosion/Soil Loss
Obstacle 4	Weed Control/Application Timing
Obstacle 5	Time Consuming/Inconvenient
Obstacle 6	Nothing
Obstacle 7	I Don't Know

Table 5.2. Analysis of variance results for main effects and interactions at all environments investigated.

Effect	P[a] (α = 0.05)
Avg. Rating of Practices	
Practice	<0.0001
State	0.003
Awareness to resistance potential[b]	0.074
Awareness of state-specific resistance[c]	0.02
Personal experience with resistance[d]	0.889
implementing actions to minimize development of resistance[e]	<0.0001
Rotating herbicide chemistries from one year to the next	
State*awareness to resistance potential[f]	0.222
State*awareness of state-specific resistance[g]	0.594
State*personal experience with resistance[h]	0.578
State*implementing actions to minimize development of resistance[i]	0.409
Awareness to resistance potential[b]	0.272
Awareness of state-specific resistance[c]	0.05
Personal experience with resistance[d]	0.408
Implementing actions to minimize development of resistance[e]	<0.0001
Tillage	
State*awareness to resistance potential[f]	0.696
State*awareness of state-specific resistance[g]	0.561
State*personal experience with resistance[h]	0.96
State*implementing actions to minimize development of resistance[i]	0.215
Awareness to resistance potential[b]	0.188
Awareness of state-specific resistance[c]	0.967
Personal experience with resistance[d]	0.122
Implementing actions to minimize development of resistance[e]	0.348

(Continued)

Table 5.2. (Continued)

Effect	P[a] (α = 0.05)
Rotating crops	
State*awareness to resistance potential[f]	0.757
State*awareness of state-specific resistance[g]	0.4
State*personal experience with resistance[h]	0.702
State*implementing actions to minimize development of resistance[i]	0.773
Awareness to resistance potential[b]	0.317
Awareness of state-specific resistance[c]	0.939
Personal experience with resistance[d]	0.68
Implementing actions to minimize development of resistance[e]	0.023
Using the correct label rates of herbicide at the proper timing for the size and type of weeds present	
State*awareness to resistance potential[f]	0.9644
State*awareness of state-specific resistance[g]	0.433
State*personal experience with resistance[h]	0.883
State*implementing actions to minimize development of resistance[i]	0.957
Awareness to resistance potential[b]	0.061
Awareness of state-specific resistance[c]	0.37
Personal experience with resistance[d]	0.092
Implementing actions to minimize development of resistance[e]	<0.0001
Using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide	
State*awareness to resistance potential[f]	0.159
State*awareness of state-specific resistance[g]	0.083
State*personal experience with resistance[h]	0.7
State*implementing actions to minimize development of resistance[i]	0.107
Awareness to resistance potential[b]	0.754
Awareness of state-specific resistance[c]	0.0002
Personal experience with resistance[d]	0.136
Implementing actions to minimize development of resistance[e]	<0.0001

(Continued)

Table 5.2. (Continued)

Effect	P[a] (α = 0.05)
Using more than one herbicide chemistry in a given year such as glyphosate and another post-applied herbicide	
State*awareness to resistance potential[f]	0.314
State*awareness of state-specific resistance[g]	0.553
State*personal experience with resistance[h]	0.57
State*implementing actions to minimize development of resistance[i]	0.916
Awareness to resistance potential[b]	0.718
Awareness of state-specific resistance[c]	0.003
Personal experience with resistance[d]	0.423
Implementing actions to minimize development of resistance[e]	<0.0001
Rotating away from a Roundup Ready crop to a non-Roundup Ready crop	
State*awareness to resistance potential[f]	0.681
State*awareness of state-specific resistance[g]	0.345
State*personal experience with resistance[h]	0.667
State*implementing actions to minimize development of resistance[i]	0.11
Awareness to resistance potential[b]	0.099
Awareness of state-specific resistance[c]	0.316
Personal experience with resistance[d]	0.244
Implementing actions to minimize development of resistance[e]	<0.0001

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Responses to the question, “Are you aware of the potential for weeds to develop resistant to glyphosate herbicides?”
[c] Responses to the question, “Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?”
[d] Responses to the question, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?”
[e] Responses to the question, “Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm?”
[f] Interaction between the responses to the question, “Are you aware of the potential for weeds to develop resistant to glyphosate herbicides?” and state.
[g] Interaction between the responses to the question, “Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?” and state.
[h] Interaction between the responses to the question, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?” and state.
[i] Interaction between the responses to the question, “Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm?” and state.

Table 5.3. Post hoc analysis of effectiveness for each resistance management practice. Means followed by the same letter are not significantly different according to Tukey's test at $P < 0.05$[a].

Practice	Mean Effectiveness Rating	MSD (0.05)
Using the correct label rates of herbicide at the proper timing for the size and type of weeds present	8.61 a	
Rotating crops	7.31 b	
Rotating herbicide chemistries from one year to the next	7.18 bc	
Using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide	6.95 cd	0.31
Using more than one herbicide chemistry in a given year such as glyphosate and another post-applied herbicide	6.87 cd	
Rotating away from a Roundup Ready crop to a non-Roundup Ready Crop	6.76 d	
Tillage	5.49 e	

[a] Abbreviations: MSD, minimum significant difference.

Table 5.4. Post hoc analysis of each state and mean effectiveness rating for all glyphosate resistant management practices. Means followed by the same letter are not significantly different according to Tukey's test at $P < 0.05$[a].

State	Mean Effectiveness Rating	MSD (0.05)
Mississippi	7.27 a	
North Carolina	7.08 ab	
Iowa	7.04 ab	0.28
Nebraska	6.99 b	
Illinois	6.92 b	
Indiana	6.9 b	

[a] Abbreviations: MSD, minimum significant difference.

Table 5.5. Post hoc analysis different levels of grower awareness and mean effectiveness rating for all glyphosate resistant management practices. Means followed by the same letter are not significantly different according to Tukey's test at $P < 0.05$[a].

Variable	Mean Effectiveness Rating	MSD (0.05)
Awareness to resistance potential[b]		
Yes	7.01 a	0.49
No	7.44 a	
Awareness of state-specific resistance[c]		
Yes	7.15 a	0.18
No	6.93 b	
Personal experience with resistance[d]		
Yes	7.04 a	0.24
No	6.03 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.28 a	0.19
No	6.52 b	

[a] Abbreviations: MSD, minimum significant difference.
[b] Responses to the question, "Are you aware of the potential for weeds to develop resistant to glyphosate herbicides?"
[c] Responses to the question, "Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?"
[d] Responses to the question, "Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?"
[e] Responses to the question, "Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm?"

Table 5.6. Post hoc analysis of different levels of grower awareness and mean effectiveness rating for each practice aimed at preventing the development of GR weeds. Means followed by the same letter are not significantly different according to Tukey's test at $P < 0.05$[a].

Variable	Mean Effectiveness Rating	MSD (0.05)
Rotating herbicide chemistries from one year to the next		
Awareness to resistance potential[b]		
Yes	7.16 a	0.79
No	7.67 a	
Awareness of state-specific resistance[c]		
Yes	7.35 a	0.3
No	7.05 a	
Personal experience with resistance[d]		
Yes	7.04 a	0.39
No	7.21 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.58 a	0.31
No	6.35 b	
Tillage		
Awareness to resistance potential[b]		
Yes	5.48 a	0.89
No	5.84 a	
Awareness of state-specific resistance[c]		
Yes	5.50 a	0.33
No	5.48 a	
Personal experience with resistance[d]		
Yes	5.75 a	0.43
No	5.43 a	
Implementing actions to minimize development of resistance[e]		
Yes	5.57 a	0.36
No	5.34 a	
Rotating crops		
Awareness to resistance potential[b]		
Yes	7.29 a	0.80
No	7.95 a	
Awareness of state-specific resistance[c]		
Yes	7.31 a	0.30
No	7.31 a	
Personal experience with resistance[d]		
Yes	7.20 a	0.39
No	7.34 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.45 a	0.32
No	6.03 b	

(Continued)

Table 5.6. (Continued)

Variable	Mean Effectiveness Rating	MSD (0.05)
Using the correct label rates of herbicide at the proper timing for the size and type of weeds present		
Awareness to resistance potential[b]		
Yes	8.59 a	0.61
No	9.10 a	
Awareness of state-specific resistance[c]		
Yes	8.67 a	0.23
No	8.57 a	
Personal experience with resistance[d]		
Yes	8.41 a	0.29
No	8.65 a	
Implementing actions to minimize development of resistance[e]		
Yes	8.77 a	0.24
No	8.28 b	
Using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide		
Awareness to resistance potential[b]		
Yes	6.94 a	0.77
No	7.16 a	
Awareness of state-specific resistance[c]		
Yes	7.26 a	0.29
No	5.48 b	
Personal experience with resistance[d]		
Yes	7.19 a	0.37
No	6.90 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.24 a	0.30
No	6.36 a	
Using more than one herbicide chemistry in a given year such as glyphosate and another post-applied herbicide		
Awareness to resistance potential[b]		
Yes	6.87 a	0.78
No	7.86 a	
Awareness of state-specific resistance[c]		
Yes	7.12 a	0.29
No	6.68 b	
Personal experience with resistance[d]		
Yes	7.00 a	0.37
No	6.84 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.13 a	0.30
No	6.34 b	

(Continued)

Table 5.6. (Continued)

Variable	Mean Effectiveness Rating	MSD (0.05)
Rotating away from a Roundup Ready crop to a non-Roundup Ready crop		
Awareness to resistance potential[b]		
Yes	6.73 a	0.89
No	7.48 a	
Awareness of state-specific resistance[c]		
Yes	6.85 a	0.34
No	6.69 a	
Personal experience with resistance[d]		
Yes	6.55 a	0.44
No	6.80 a	
Implementing actions to minimize development of resistance[e]		
Yes	7.16 a	0.35
No	5.93 b	

[a] Abbreviations: MSD, minimum significant difference.
[b] Responses to the question, “Are you aware of the potential for weeds to develop resistant to glyphosate herbicides?”
[c] Responses to the question, “Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?”
[d] Responses to the question, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?”
[e] Responses to the question, “Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm?”

Table 5.7. Chi-square analysis of obstacles identified to manage potential resistance to glyphosate, and obstacles by variable combinations used in the analysis.

Variables	P[a] (α = 0.05)
Obstacles	0.018
Obstacles*Practice	<0.0001
Obstacles*State	0.153
Obstacles*Awareness to resistance potential[f]	0.390
Obstacles *Awareness of state-specific resistance[g]	0.002
Obstacles *Personal experience with resistance[h]	<0.0001
Obstacles *Implementing actions to minimize development of resistance[i]	0.069

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).
[b] Interaction between the responses to the question, "Are you aware of the potential for weeds to develop resistant to glyphosate herbicides?" and obstacles.
[c] Interaction between the responses to the question, "Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?" and obstacles.
[d] Interaction between the responses to the question, "Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?" and obstacles.
[e] Interaction between the responses to the question, "Are you doing anything specific in your weed management program, including tillage, herbicides, or crop rotation, to minimize the potential for weeds to develop resistance to glyphosate on your farm?" and obstacles.

Table 5.8. Chi-square analysis of obstacles to adoption of practices identified to manage potential resistance to glyphosate.

Obstacles to Adopting Practices	Frequency of Responses (n=3754)
	----------%(number of responses/obstacle)----------
Weather	
% within obstacle	6(241)
Cost	
% within obstacle	14(542)
Soil loss	
% within obstacle	1(33)
Weed control	
% within obstacle	8(287)
Inconvenience	
% within obstacle	2(75)
Nothing	
% within obstacle	67(2508)
I don't know	
% within obstacle	2(68)

Table 5.9. Summary of obstacle distribution among each of the seven practices aimed at minimizing the development of glyphosate resistance in weeds.

Obstacles to Adopting Practices	Rotating herbicide chemistries from one year to the next	Tillage	Rotating crops	Using the correct label rates of herbicides at the proper timing for the size and type of weeds present
	(n=535)	(n=283)	(n=573)	(n=906)
Weather (n=241)				
% within obstacle	2	8	3	75
% within practice	1	7	1	20
Cost (n=542)				
% within obstacle	12	9	11	11
% within practice	12	17	11	6
Soil Loss (n=33)				
% within obstacle	0	85	6	0
% within practice	0	10	0	0
Weed Control (n=287)				
% within obstacle	19	2	5	28
% within practice	10	2	2	9
Inconvenience (n=75)				
% within obstacle	20	0	12	7
% within practice	3	0	2	1
Nothing (n=2508)				
% within obstacle	15	7	19	23
% within practice	72	62	82	63
I Don't Know (n=68)				
% within obstacle	13	9	18	16
% within practice	2	2	2	1
Total (n=3754)				
% within obstacle	14	8	15	24
% within practice	-	-	-	-

(Continued)

Table 5.9. (Continued)

Obstacles to Adopting Practices	Using more than one herbicide chemistry in a given year such as glyphosate and a residual herbicide (n=471)	Using more than one herbicide chemistry in a given year such as glyphosate and another post-applied herbicide (n=466)	Rotating away from a Roundup Ready crop to a non-roundup Ready crop (n=520)	Total (n=3754)
Weather (n=241)				
% within obstacle	5	3	4	-
% within practice	2	1	2	6
Cost (n=542)				
% within obstacle	21	23	13	-
% within practice	24	26	13	14
Soil Loss (n=33)				
% within obstacle	0	0	9	-
% within practice	0	0	1	1
Weed Control (n=287)				
% within obstacle	9	9	28	-
% within practice	6	6	15	8
Inconvenience (n=75)				
% within obstacle	11	18	32	-
% within practice	2	3	5	2
Nothing (n=2508)				
% within obstacle	12	11	13	-
% within practice	64	61	62	67
I Don't Know (n=68)				
% within obstacle	10	18	16	-
% within practice	2	3	2	2
Total (n=3754)				
% within obstacle	13	12	14	-
% within practice	-	-	-	-

[a] P values were calculated with chi-square analysis in SAS 9.2 (Statistical Analysis Systems Institute, Cary, NC).

Table 5.10. Summary of obstacle distribution among grower awareness of glyphosate resistant weeds in their state.

Obstacles to Adopting Practices	Responses to Question 12a[a] Yes (n=589)	No (n=512)	Total (n=1101)
Weather (n=71)			
% within obstacle	59	41	-
% within question	7	6	6
Cost (n=381)			
% within obstacle	51	49	-
% within question	33	37	35
Soil loss (n=32)			
% within obstacle	69	31	-
% within question	4	2	3
Weed control (n=257)			
% within obstacle	51	49	-
% within question	22	24	23
Inconvenience (n=72)			
% within obstacle	64	36	-
% within question	8	5	7
Nothing (n=221)			
% within obstacle	48	52	-
% within question	18	22	20
I don't know (n=67)			
% within obstacle	72	28	-
% within question	8	4	6
Total (n=1101)			
% within obstacle	54	46	-
% within question	-	-	-

[a] Responses to the question, "Are you aware of any specific weeds in your state that have been documented to be resistant to glyphosate herbicide?"

Table 5.11. Summary of obstacle distribution among grower personal experience with glyphosate resistant weeds.

Obstacles to Adopting Practices	Responses to Question 13a[a] Yes (n=830)	No (n=2787)	Total (n=3617)
Weather (n=236)			
% within obstacle	35	65	-
% within question	10	5	6
Cost (n=525)			
% within obstacle	30	70	-
% within question	19	13	14
Soil loss (n=32)			
% within obstacle	78	22	-
% within question	3	0	1
Weed control (n=277)			
% within obstacle	39	61	-
% within question	13	6	8
Inconvenience (n=72)			
% within obstacle	74	26	-
% within question	6	1	2
Nothing (n=2408)			
% within obstacle	15	85	-
% within question	43	74	67
I don’t know (n=67)			
% within obstacle	70	30	-
% within question	6	1	2
Total (n=3617)			
% within obstacle	23	77	-
% within question	-	-	-

[a] Responses to the question, “Have you personally experienced any weeds on your farm that are resistant to glyphosate herbicides?”