Glyphosate-Induced Weed Shifts'

A. STANLEY CULPEPPER2

Abstract: Composition and abundance of weed populations often change in response to new or extensively used weed management practices. Glyphosate-resistant (GR) technology is one such weed management practice now used extensively. A recent survey of weed scientists was conducted to address weed shifts in GR corn, cotton, and soybean. Twelve scientists in 11 states responded to the survey. Averaged over estimates from scientists, GR corn, cotton, and soybean were planted on 15, 90, and 88% of the hectarage in 2003, respectively. Acreage of GR corn is expected to rise, whereas only minor changes in acreage of GR cotton or soybean are expected. Weed shifts have not been observed in GR corn but have occurred in GR cotton and soybean. In GR cotton, *Amaranth us, Commelina, Ipomoea,* and *Cyperus* species as well as annual grasses were noted as becoming more problematic. Similar to cotton, *Ipomoea* and *Commelina* species are becoming more troublesome in GR soybean. In addition, in GR soybean, various winter annuals, lambsquarters species, and waterhemp species were noted as becoming more problematic. All scientists felt that weeds shifts were occurring, and two-thirds of these scientists noted that weed shifts are currently of economic concern. The scientists recommend the following to help manage weed shifts: additional herbicides in mixture with glyphosate, rotation to herbicides other than glyphosate, rotation to non–GR crops, and greater use of soil-applied herbicides.

Nomenclature: Glyphosate; waterhemp species, *Amaranthus tuberculatus* and *Amaranthus rudis;* corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; soybean, *Glycine max (L.)* Merr.

Additional index words: Invasive weeds, noxious weeds.

Abbreviation: GR, glyphosate-resistant.

INTRODUCTION

Adoption of biotechnology crops has risen dramatically since commercial approval in the mid-1990s. At least 68, 56, and 9% of the U.S. soybean, cotton, and corn hectarage, respectively, were planted to herbicide-resistant crops in 2001, with most of the hectarage being planted to glyphosate-resistant (GR) crops (Fernandez-Cornejo and McBride 2002). Widespread adoption of GR technology is, in part, because of the following: the opportunity to reduce or eliminate soil-applied herbicides and to reduce total herbicide use (Culpepper and York 1998, 1999), more effective weed management options in conservation tillage systems (Bradley 2000), greater rotational crop flexibility (Bradley et al. 2001; Rogers et al. 1986; York 1993), the capability to control previously uncontrollable weeds (Byrd 1995), and additional herbicide chemistry to use in resistance management programs (Shaw 1995). However, of greatest interest to growers is the economical, broad-spectrum weed control and convenience of postemergence over-the-top application of glyphosate without crop injury (Wilcut et al. 1996).

Introduction and intense adoption of new weed management tools often result in a shift in the population of the weed flora. These shifts often change the weed composition from more susceptible to more tolerant species and is true for both chemical and nonchemical control methods (Aldrich and Kremer 1997; Culpepper et al. 2004; Marshall et al. 2000; Tuesca et al. 2001). Weed shifts often occur more rapidly in response to changes in chemical control tactics than selection of resistant weed populations (Shaner 2000). Data addressing the potential for weed shifts in GR crops when using glyphosate-based weed management programs are extremely limited. Available data suggest few significant changes in weedy populations have occurred in research plots (Curran et al. 2002; Harker et al. 2004; Hayes 2000; Westra and Nissen 2004). Although significant weed

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Assistant Professor, Department of Crop and Soil Sciences, University of Georgia, P.O. Box 1209, Tifton, GA 31794. Corresponding author's E-mail: stanley@uga.edu.

Table 1. Weed scientists responding to the glyphosate-induced weed shift survey and their respective crops.[a]

Weed scientists	Location/institution	State	GR crops
Barry J. Brecke	University of Florida	Florida	Corn, cotton, soybean
Todd A. Baughman	Texas A&M University	Texas	Corn, cotton, soybean
A. Stanley Culpepper	University of Georgia	Georgia	Corn, cotton, soybean
William Curran	Penn State University	Pennsylvania	Corn, soybean
J. Andrew Kendig	University of Missouri	Missouri	Corn, cotton, soybean
Mark Loux	Ohio State University	Ohio	Corn, soybean
Michael Owen	Iowa State University	Iowa	Corn, soybean
Mike Patterson	Auburn University	Alabama	Corn, cotton, soybean
Christy Sprague[b]	University of Illinois	Illinois	Corn, soybean
Mark VanGessel	University of Delaware	Delaware	Corn, soybean
Bryan Young	Southern Illinois University	Illinois	Corn, soybean
Alan York	North Carolina State University	North Carolina	Corn, cotton, soybean

[a] Abbreviation: GR, glyphosate resistant.

[b] At the time of survey, Dr. Sprague was employed at the University of Illinois but is currently at Michigan State University.

shifts have not been observed in small-plot research, some species are becoming very problematic in growers' fields. An example would be tropical spiderwort *(Commelina benghalensis L.).* Tropical spiderwort has become very troublesome in GR crops in Georgia and is spreading rapidly because, at least in part, of dependence on glyphosate-based weed management programs, which often only suppress the weed (Culpepper et al. 2004; Prostko et al. 2004). Because little information is available regarding weed shifts in GR crops and because it is questionable whether small-plot research can truly detect weed shifts accurately, a survey was conducted to further understand the ongoing and potential changes in weed population dynamics in response to intense adoption of GR technology and the associated weed management programs.

METHODS

A survey was sent to weed scientists across the United States with respect to weed shifts in GR crops. Four scientists from both the southeastern and midwestern United States as well as two from the northeast United States and two from the southern United States responded to the survey (Table 1). Each scientist was asked seven questions (Table 2), and their responses were compiled. All scientists responded to questions regarding GR corn and soybean, whereas only six scientists from the southern and southeastern United States responded to questions regarding GR cotton.

RESULTS AND DISCUSSION

Question 1: Estimate the Percentages of Hectares Planted to GR Corn, Cotton, and Soybean in 1997, 2000, and 2003. Averaged over the 11 states and 12 weed scientists, GR soybean hectarage estimates were 27, 78, and 88% in 1997, 2000, and 2003, respectively. Scientists from the six states where cotton is grown reported cotton hectarage adoption very similar to that noted in soybean, with 23, 83, and 90% of the acreage planted to GR cotton in 1997, 2000, and 2003, respectively. GR corn was not planted on any reported acreage in 1997 or in 2000. GR corn was not commercialized until 1998, and, even after commercialization, hybrid selection limited its adoption for several years. By 2003, however, 15% of the corn hectarage was planted to GR hybrids.

Question 2: Do You Anticipate Changes in the Percentages of Hectares Planted to GR Crops? GR cotton and soybean are already planted on 88 to 90% of the hectarage represented in this survey. Changes in percentage of GR cotton and soybean are expected to be

Table 2. Questions posed to weed scientists regarding GR crops and potential weed shifts in those crops.[a]

1. Estimate the percentage of acres planted to GR corn, cotton, and soybean in 1997, 2000, and 2003.
2. Do you anticipate changes in the percentages of acres planted to GR crops?
3. Are weed shifts occurring, and if so, are they of economic concern?
4. If shifts are occurring, list those weed species that are increasing in each GR crop.
5. Are there other species for which you anticipate future shifts?
6. If shifts are occurring, are the shifts solely in response to glyphosate use?
7. What recommendations are you making to help growers manage weed shifts?

[a] Abbreviation: GR, glyphosate resistant.

minor. Several scientists did suggest that GR cotton hectarage may drop somewhat with the release of cultivars resistant to glufosinate and commercialization of the herbicide trifloxysulfuron in 2004. Both these new cotton weed control technologies offer growers effective weed management alternatives to GR technology. Of the 12 scientists, 10 felt that GR corn hectarage would increase quickly. The major reason for this expected increase in GR corn hectarage is the release of new high-performing GR hybrids from Pioneer Hi-Bred International.

Question 3: Are Weed Shifts Occurring, and if so, Are They of Economic Concern? On the basis of the survey, 100% of the scientists felt that weed shifts were occurring in their areas, and 67% of the scientists felt that these shifts are currently of economic concern. Thirty-three percent of the scientists felt that these shifts were not of economic concern because growers were able to manage weed population changes with minor changes in management and without economic burden, similar to research by Curran et al. (2002). However, two-thirds of the scientists felt that shifts in population dynamics were causing the addition of other weed management tactics, thereby increasing the cost of weed management programs. For example, tropical spiderwort has adapted very quickly to GR cotton weed management programs in the southeastern United States. Use of additional herbicides to control this weed has typically increased costs at least 33%, and control is still often unacceptable (Culpepper et al. 2004).

Question 4: If Shifts Are Occurring, List Those Weed Species That Are Increasing in Each GR Crop. In GR cotton, the five most common weed species mentioned by scientists included *Ipomoea* (66% of scientists), *Commelina* (50% of scientists), *Amaranthus* (50% of scientists), and *Cyperus* species (33% of scientists) as well as annual grasses (33% of scientists). *Ipomoea*, *Commelina*, and *Cyperus* species are becoming more common in fields because growers often conduct little to no tillage and rely heavily on glyphosate. Control of these weeds by glyphosate is often inadequate (Barivan et al. 1999; Culpepper et al. 2004; Ellis and Griffin 2003; Fischer and Harvey 2002; Nelson and Renner 2002). *Amaranthus* and annual grasses are effectively controlled by glyphosate (Askew and Wilcut 1999; Jordan et al. 1997), but these species germinate throughout the season and often emerge after glyphosate application (Tharp and Kells 2002). Growers have reduced or eliminated use of residual herbicides in GR cotton. Without residual herbicides, weeds such as annual grasses and *Amaranthus* that germinate after the final glyphosate application are able to produce seed and reduce harvesting efficiency and aesthetic value.

Similar to cotton, *Ipomoea* (50% of scientists) and *Commelina* (30% of scientists) species were among the five most common weeds mentioned as becoming more problematic in GR soybean. Winter annuals (50% of scientists), lambsquarters species (30% of scientists), and waterhemp species (30% of scientists) were also noted as weeds that have become more troublesome. Adoption of conservation tillage is allowing winter annuals to become more prevalent. In addition, several winter annuals, such as cutleaf eveningprimrose (*Oenothera laciniata* Hill), are difficult to manage with glyphosate (Culpepper et al. 2002). Reduced tillage, coupled with glyphosate-tolerant winter annual weeds, has increased the number of troublesome weeds in GR soybean. Similarly, lambsquarters species are often difficult to manage with glyphosate (Taylor-Lovell et al. 2002; Tharp and Kells 2002) and are becoming more common. Several scientists have noted lambsquarters as well as waterhemp species may be developing greater tolerance to glyphosate after repetitive applications (Patzoldt et al. 2002; Westra et al. 2004).

According to the survey, weed shifts have not yet occurred in GR corn because adoption of this technology is still relatively new. However, concern was expressed by nearly all the weed scientists. The scientists believe adoption of GR corn would be very high during the next few years, leading to a greater potential for additional and more intense shifts in GR crops.

Question 5: Are There Other Species for Which You Anticipate Future Shifts? Responses to this question were not consistent. Three scientists mentioned *Amaranthus* species, annual grasses, and *Chenopodium* species, two scientists mentioned giant ragweed (*Ambrosia trifida* L.) and *Acalypha* species, and one scientist mentioned curly dock (*Rumex crispus* L.), *Commelina* species, *Physalis* species, *Cyperus* species, and *Polygonum* species. Many of these species were chosen either for their ability to tolerate glyphosate or for their ability to emerge after the last glyphosate application in a glyphosate-based weed management program.

Question 6: If Shifts Are Occurring, Are the Shifts Solely in Response to Glyphosate Use? Shifts are not solely due to the use of glyphosate but are the result of multiple factors, which include greater adoption of conservation tillage, reduced tillage in GR crops, and less use of herbicides with residual activity. Weed shifts were occurring from the adoption of conservation tillage before the advent of GR crops (Tuesca et al. 2001). However, the commercialization of herbicide-resistant crops has facilitated continued expansion of conservation tillage (Fawcett and Towery 2003). In North Carolina, for example, less than 5% of the cotton was planted in conservation tillage in 1992, as compared with 9, 19, 30, and 40% in 1996, 1998, 2000, and 2002, respectively (CTIC 2004).

Conservation tillage has increased and use of herbicides with residual activity has decreased as GR technology has been adopted (Young 2004). As a result of these two trends, growers rely heavily or completely on glyphosate for weed management. Weeds that are tolerant to glyphosate or emerge after glyphosate applications often escape glyphosate-based weed management programs; however, many of these weeds would likely be controlled if tillage or residual herbicides were used more effectively.

Question 7: **What Recommendations Are You Making to Help Growers Manage Weed Shifts?** Scientists responded to this question with the following four recommendations to manage glyphosate-induced weed shifts: including other herbicides with glyphosate, rotation with non-GR crops, use of herbicides other than glyphosate, and greater use of soil-applied herbicides.

The most common and realistic method (10 of 12 scientists) to manage weed shifts economically is by recommending a tank-mix partner with glyphosate to improve control of troublesome weed species. Much work has been done in this area, and, in many cases, (Culpepper et al. 2004; Ellis and Griffin 2003; Tharp and Kells 2002) it is very effective and often the most economical approach to manage weed shifts. Four of 12 scientists felt that growers should rotate away from GR crops and use of glyphosate. However, the other eight scientists were of the opinion that weed shifts are not currently of enough concern to drive growers away from GR technology and dependence on glyphosate. Three of 12 scientists felt that soil-applied herbicides were an additional tool that could be recommended as part of a glyphosate-based program. Nine scientists felt that although this would be extremely effective, growers would not currently adopt this practice because it would increase herbicide costs as well as labor and equipment costs as additional herbicide applications would likely be required.

CONCLUSIONS

Growers have quickly adopted GR cotton and soybean and, although adoption of GR corn has been relatively slow since its commercialization, acreage is likely to grow quickly during the next several years. Weed shifts are occurring in response to currently used glyphosate-based weed management programs in GR crops, and these shifts are increasing weed management costs for growers. For the most part, growers are presently addressing weed shifts by adding other herbicides in combination with glyphosate.

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