GLYPHOSATE RESISTANCE IN CROPS AND WEEDS — ISSUES TO CONSIDER FOR 2005

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Introduction

Glyphosate-resistant (aka Roundup Ready) crops are now grown on 11 percent of corn and 81 percent of soybean acres in the U.S. This could continue to increase as Bt and Roundup Ready genes are stacked into more corn hybrids. Reliance on glyphosate for weed burndown before planting and in Roundup Ready crops has placed, or will place, heavy selection pressure on weeds that could develop resistance to this herbicide. Glyphosate rates used in Roundup Ready soybeans have increased steadily since its introduction in 1996, suggesting that biotypes with greater tolerance have been selected in a number of weed species. Within the North Central region, populations of field bindweed resistant to glyphosate in Indiana were reported in the 1980s and populations of horseweed resistant to glyphosate were reported in 2002. In addition, there is increasing evidence that common waterhemp and common ragweed biotypes have developed resistance to glyphosate in other states.

The purpose of this report is twofold: the first objective is to present results from the Indiana horseweed survey project, the second objective is to discuss research results from Roundup Ready corn trials and discuss appropriate management strategies to maximize yield and minimize selection pressure for additional glyphosate-resistant weed biotypes.

Indiana Horseweed Survey

A three-year sampling project was initiated in 2003 to map the distribution of glyphosate-resistant horseweed in Indiana. Survey sites were randomly selected by examining NASS Cropland Data Layer and U.S. Geological Service digitized imagery. The number of sites in each county was based upon a target of one field for every 3,000-6,000 acres of cropland. The survey sites were visited in September or October just prior to soybean harvest. At each site, identity and percent field coverage of each weed protruding above the soybean canopy was recorded. If horseweed was present, additional notes on the distribution (patchy versus uniform distribution), and appearance of escaped plants (damaged versus undamaged by a herbicide) was recorded. In addition, seed heads from 20-40 plants were collected and brought back to the greenhouse for glyphosate screening.

Results from 2003

In 2003, sampling efforts were focused in the southeastern region where horseweed escapes were prevalent in 2001, 2002, and 2003. We also collected information from two counties in each of the northeast, northwest, and southwest quadrants of the state. Survey information was collected from 792 fields and seed samples were collected from 388 of these sites.

The predominant weeds in northeastern Indiana were giant ragweed (28 percent of the fields sampled), giant foxtail (12 percent), and horseweed, common lambsquarters, cocklebur, and waterhemp (4 percent each). In northwest Indiana, the predominant weeds were giant ragweed and giant foxtail (8 percent each), barnyardgrass (6 percent), fall panicum (5 percent), and horseweed, common lambsquarters, redroot/smooth pigweed, and volunteer corn (4 percent each). In southeast Indiana, the predominant weeds were horseweed (47 percent), giant ragweed (17 percent), giant foxtail (7 percent), and common lambsquarters and fall panicum (5 percent each).

Weeds found in all three regions included horseweed (30 percent of all fields), giant ragweed (26 percent), giant foxtail (8 percent), common lambsquarters and fall panicum (5 percent), cocklebur (4 percent), barnyardgrass (3 percent), waterhemp and volunteer corn (2 percent each).

To date we have screened 352 of the 2003 populations for tolerance to a 2X rate (1.5 lb. ae/acre) of glyphosate. Some degree of resistance was noted in 116 of 352 samples (33 percent). We confirmed resistance to glyphosate in 19 Indiana counties, as far north as Wells and Blackford counties in northeast Indiana, Spencer county in southwest Indiana, and Montgomery county in west central Indiana.

Results from 2004

In 2004, a one-two county wide band surrounding the southeast region sampled in 2003 was investigated. The counties extended east from Tippecanoe County to Jay County (eastern state line) and south from Tippecanoe County to Warrick County (southern state line) in the southwest region of the state. There were 334 sites surveyed, and 62 horseweed samples collected for glyphosate herbicide screening.

The region sampled in 2004 contained fewer weed escapes overall than the region sampled in 2003. Twenty-four percent of the fields surveyed did not have weeds protruding through the canopy. The predominant weeds found included giant ragweed (51 percent of all fields), common lambsquarters (20 percent), horseweed (16 percent), giant foxtail (13 percent), pigweed (10 percent), common ragweed (7 percent), cocklebur (6 percent), velvetleaf (5 percent), waterhemp (4 percent), morning-glory (4 percent), fall panicum (3 percent), common pokeweed (2 percent), and volunteer corn (2 percent). Glyphosate screening is under way for the horseweed samples collected in 2004.

Weed Management in Glyphosate-Resistant Corn

As mentioned earlier, it is anticipated that Roundup Ready corn use will increase as insect-resistant traits are stacked into hybrids and growers become more accustomed to relying on postemergence weed management strategies in corn. Results from research papers published by Gower, et al., (2003) and Johnson, et al., (2000) will be used to highlight issues crop producers should consider if they adopt this technology.

A regional project investigated the effectiveness of total postemergence weed control programs using only glyphosate in Roundup Ready corn (Gower, et al. 2003). A total of 35 experiments were conducted in nine Midwest states. Most sites had high weed densities. Glyphosate was applied at several times during the growing season based on the size of the dominant weeds in the field. The impact of late-emerging weeds on mid-season weed control is illustrated in Table 1. Overall weed control increased as applications were delayed. For example, a single application when weeds were 12 inches tall resulted in 95 percent control, whereas spraying 2-inch weeds resulted in only 73 percent control. The reduced weed control was due to weeds that emerged after application, rather than an inability of glyphsate to kill the larger weeds. Looking only at weed control would suggest that delaying herbicide applications is an effective strategy to enhance weed control.

In this study, treatments were included that determined yield loss associated with the weeds that emerged with the crop, controlled at a specific height, and the plots kept weed-free for the remainder of the season (see footnote 1 in Table 1). The study also included treatments that utilized a single postemergence treatment of glyphosate and weeds were allowed to naturally re-infest the area after treatment (see footnote 2 in Table 1). Corn subjected only to weed competition from emergence to postemergence application began to suffer yield losses when herbicide application was made to 4-inch tall weeds (Table 1). Applying the herbicide when weeds were 4 inches tall resulted in a 3 percent yield loss, and each delay approximately doubled yield loss. The reduction in corn yields due to competition prior to the postemergence application illustrates the risk of delaying treatment in hopes of minimizing problems with late emerging weeds.

Although early applications (weeds 2-4 inches) minimized competition from weeds that emerged with the crop, weeds emerging after the early application were able to compete with the corn and reduce yields. If you compare the yield losses in both sets of treatments at the 4-inch application timing, weeds emerging after the 4-inch application timing added an additional 3 percent yield loss to the 3 percent loss caused by early-season competition. This study illustrates the difficulty in obtaining maximum yields with a single postemergence applications of herbicides without residual activity.

Table 1. The effect of application timing on weed control and corn yields.

Application timing (weed size in inches)	Weed control	Corn yield loss[1] (Early-season competition only)	Corn yield loss[2] (Early- and late season competition)
	-------------------	%	-------------------
2	73	0	7
4	83	3	6
6	90	6	7
9	93	14	11
12	95	22	21

[1] Weeds emerging after herbicide application controlled with hand weeding.
[2] Weeds allowed to emerge after herbicide application and compete with corn for the remainder of the growing season.

In another study published in Weed Technology, field experiments were conducted in Missouri and Illinois to evaluate weed control and corn yield provided by various weed control programs in Roundup Ready corn. The herbicide programs evaluated included a reduced rate of Harness preemergence followed by glyphosate with or without atrazine postemergence and total postemergence programs consisting of single and sequential applications of glyphosate alone and tankmixed with Harness, atrazine or both.

In the total postemergence treatments, mid-post (weeds 4-6 inches tall) applications generally provided better mid-season annual grass control than early-post (weeds 1-3 inches tall) applications (Table 2). Early postemergence treatments containing Harness provided 20-25 percent better annual grass control than those that did not.

The addition of Harness and atrazine to postemergence glyphosate generally increased control of annual broadleaf weeds (Table 3). Annual broadleaf weed control was poor with glyphosate alone. The best control was obtained with two applications of glyphosate or with herbicide combinations that included Harness and atrazine in various application strategies with glyphosate.

Early postemergence treatments of glyphosate + atrazine or glyphosate + atrazine + Harness or preemergence fb, generally provided higher yields than mid-postemergence treatments, although mid-postemergence treatments often provided equal or greater weed control at mid-season (Table 4). Treatments including two herbicide applications tended to provide greater weed control, yield, and profit than those with single applications.

Most weed managers realize that the objective of weed management is not only to control weeds, but also to protect yields. A risk associated with the new herbicides that provide consistent control of large weeds is that treatment may be delayed until after weeds have already reduced corn yields. Corn and soybeans are able to tolerate weed competition for a limited time after emergence without yields being affected. At some point, however, weeds reduce the availability of water, sunlight, or nutrients and reduce the yield potential of the crop. The specific time when this occurs varies from field to field, and is affected by weed infestations (species, densities), weather conditions, and many other factors. In fields with moderate to heavy weed populations, this research shows that weeds may begin to affect yields after reaching a height of only 3-4 inches.

New postemergence technology provides farmers greater flexibility to manage weeds in corn. However, these tools require careful management to maximize productivity. The nature of weeds makes it difficult to consistently achieve acceptable weed control and protect yields with a single herbicide application. Farmers need to develop integrated weed management programs to consistently achieve high yields and good weed control. This can be achieved by applying a preemergence herbicide to suppress early emerging weeds, therefore minimizing the risk of delaying postemergence applications until the crop canopy has developed to the point where it can suppress late-emerging weeds. Where a broad-spectrum postemergence herbicide is part of the planned program, a full rate of the preemergence herbicide is usually unnecessary. An alternative approach is to plan on two postemergence applications, with the first applied early in the season before there is any risk of early-season competition. Successful weed management in corn depends upon knowing the characteristics of weed infestations in individual fields, how the weeds interact with the crop, and understanding the strengths and weaknesses of the control tactics being used.

References:

Gower, Loux, Cardina, Harrison, Sprankle, Probst, Bauman, Bugg, Curran, Currie, Harvey, Johnson, Kells, Owen, Regehr, Slack, Spaur, Sprague, VanGessel and Young. 2003. Effect of postemergence glyphosate application timing on weed control and grain yield in glyphosate-resistant corn: Results of a 2-year multi-state study. Weed Technol. 17:821-828.

Johnson, Bradley, Hart, Beusinger, and Massey. 2000. Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol. 14:57-65.

Table 2. Annual grass control in Roundup Ready corn at Columbia and Novelty, Missouri and Urbana, Illinois in 1997 and 1998.

Herbicide[1]	Rate/acre	Timing[2]	Percent of annual grass control
Harness fb Glyphosate	1.12 pt. 24 oz.	PRE EPOST	82
Harness pre fb glyphosate + atrazine epost	1.12 pt. 24 oz. + 1 lb ai	PRE EPOST	90
Glyphosate	32 oz.	EPOST	65
Glyphosate fb glyphosate	24 oz. fb 16 oz.	EPOST 3” regrowth	93
Glyphosate + atrazine	32 oz. + 1 lb. ai	EPOST	76
Glyphosate + Harness	24 oz. + 1.12 pt.	EPOST	90
Glyphosate + Harness + atrazine	24 oz. + 1.12 pt. 1 lb ai	EPOST	92
Glyphosate + Harness	24 oz. + 1.12 pt.	MPOST	94
Glyphosate + Harness atrazine	24 oz. + 1.12 pt. + 1 lb.	MPOST	94

[1]All glyphosate treatments included ammonium sulfate at 2.5 lb./acre.
[2] PRE, preemergence; EPOST, early postemergence (broadleaf weeds 1-3 inches tall); MPOST, mid-postemergence (broadleaf weeds 4- 6 inches tall); Regrowth, EPOST fb Regrowth when weeds were approximately 3 inches tall.

Table 3. Annual broadleaf control in Roundup Ready corn at Columbia and Novelty, Missouri and Urbana, Illinois in 1997 and 1998.

Herbicide[1]	Rate/acre	Timing[2]	Percent annual broadleaf control
Harness fb Glyphosate	1.12 pt. 24 oz.	PRE EPOST	80
Harness pre fb glyphosate + atrazine epost	1.12 pt. 24 oz. + 1 lb ai	PRE EPOST	94
Glyphosate	32 oz.	EPOST	68
Glyphosate fb glyphosate	24 oz. fb 16 oz.	EPOST 3” regrowth	88
Glyphosate + atrazine	32 oz. + 1 lb ai	EPOST	92
Glyphosate + Harness	24 oz. + 1.12 pt.	EPOST	81
Glyphosate + Harness + atrazine	24 oz. + 1.12 pt. 1 lb ai	EPOST	94
Glyphosate + Harness	24 oz. + 1.12 pt.	MPOST	86
Glyphosate + Harness atrazine	24 oz. + 1.12 pt. + 1 lb.	MPOST	96

[1] All glyphosate treatments included ammonium sulfate at 2.5 lb./acre.
[2] PRE, preemergence; EPOST, early postemergence (broadleaf weeds 1-3 inches tall); MPOST, mid-postemergence (broadleaf weeds 4-6 inches tall); Regrowth, EPOST fb Regrowth when weeds were approximately 3 inches tall.

Table 4. Roundup Ready corn yield at Columbia and Novelty, Missouri and Urbana, Illinois in 1997 and 1998.

Herbicide[1]	Rate/acre	Timing[2]	Yield (bu./acre)
Harness fb Glyphosate	1.12 pt. 24 oz.	PRE EPOST	136
Harness pre fb glyphosate + atrazine epost	1.12 pt. 24 oz. + 1 lb ai	PRE EPOST	127
Glyphosate	32 oz.	EPOST	116
Glyphosate fb glyphosate	24 oz. fb 16 oz.	EPOST 3" regrowth	132
Glyphosate + atrazine	32 oz. + 1 lb ai	EPOST	126
Glyphosate + Harness	24 oz. + 1.12 pt.	EPOST	130
Glyphosate + Harness + atrazine	24 oz. + 1.12 pt. 1 lb ai	EPOST	126
Glyphosate + Harness	24 oz. + 1.12 pt.	MPOST	109
Glyphosate + Harness atrazine	24 oz. + 1.12 pt. + 1 lb	MPOST	118
LSD (0.05)			10

[1] All glyphosate treatments included ammonium sulfate at 3.8 kg/hectare.
[2] PRE, preemergence; EPOST, early postemergence (broadleaf weeds 1-3 inches tall); MPOST, mid-postemergence (broadleaf weeds 4- 6 inches tall); Regrowth, EPOST fb Regrowth when weeds were approximately 3 inches tall.