Comparison of Weed Control, Yield, and Net Income in Conventional, Glyphosate-Resistant, and Glufosinate-Resistant Soybean

Kristin K. Rosenbaum, Raymond E. Massey, and Kevin W. Bradley*

Abstract
Separate field experiments were conducted in central and southeast Missouri during 2009 and 2010 to evaluate the effect of preemergence (PRE) and postemergence (POST) herbicide programs on Palmer amaranth (Amaranthus palmeri S. Wats.) and waterhemp (Amaranthus rudis Sauer) control, soybean [Glycine max (L.) Merr.] yield, and net income in conventional, glyphosate-resistant, and glufosinate-resistant soybean production systems. Visual control evaluations 10 wk after emergence at the waterhemp site revealed that all preemergence only applications (PRE-only) and preemergence followed by a postemergence applications (PRE fb POST) provided greater than 92% waterhemp control in either soybean system and at the Palmer amaranth site and all PRE-only provided greater than 83% Palmer amaranth control across soybean systems. Averaged across all herbicide programs at both locations, glufosinate-resistant soybean provided the highest grain yield and net return followed by glyphosate-resistant and conventional soybean systems. Furthermore, with the exception of the conventional PRE-only program at the waterhemp site, all glyphosate-resistant soybean herbicide programs provided greater net return than all conventional herbicide programs. Collectively, the results from both trials indicate that programs containing PRE herbicide treatments provide the best opportunity for season-long control of waterhemp and Palmer amaranth and highest grain yields and net returns in conventional, glyphosate-resistant, or glufosinate-resistant soybean systems. The results from these experiments also suggest that Palmer amaranth may be particularly difficult to control in conventional soybean systems.

Problematic Weeds and Weed Management Systems

Palmer amaranth and waterhemp, both members of the Amaranthus family, are two of the most troublesome agronomic weeds in the United States due to their extended period of emergence, rapid growth at high light intensities and temperatures, and prolific seed production (10,14,18,27). In Missouri, the most common pigweed (Amaranthus spp.) species

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Abbreviations: 1-pass POST, one-pass postemergence application; 1-pass POST W/Res, one-pass postemergence application with a residual herbicide; 2-pass POST, two-pass postemergence application; ALS, acetolactate synthase; POST, ; PRE, preemergence; PRE fb POST, preemergence followed by a postemergence application; PRE-only, preemergence only application; WAE, weeks after emergence.

Published in Crop Management
DOI 10.1094/CM-2013-0028-RS
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encountered in corn (Zea mays L.) and soybean production are common or tall waterhemp. Due to the high degree of genetic similarity and hybridization between these two, many botanists now group them into one species simply referred to as “waterhemp” (24).

A variety of research has been conducted to determine the impact of Palmer amaranth or waterhemp infestations on crop yield. Palmer amaranth and waterhemp can cause significant yield reductions in corn, soybean, and cotton (Gossypium hirsutum L.) (16,18,21). Palmer amaranth has reduced corn yields from 11 to 91% at densities of 0.5 to 8 plants/m of row, reduced soybean yield from 17 to 79% at densities of 0.33 to 10 plants/m of row, and reduced cotton lint yield by 6 to 28% at densities of one plant per 1 to 3 m of row (1,16,17,18,30). Additionally, soybean biomass and yield has been reduced when growing within 20 and 10 inches of Palmer amaranth, respectively (20). Soybean yield reductions are correlated to Palmer amaranth biomass and density; as Palmer amaranth densities and biomass increase, soybean yield decreases linearly (16).

Waterhemp plants that emerged with the crop and were allowed to compete season long reduced soybean yield by 37 to 44% (32). Waterhemp that emerges before the V4 to V5 stage of soybean growth must be controlled to prevent soybean yield loss and waterhemp seed production (9,32). Furthermore, soybean seed yield was reduced 43% by allowing waterhemp to compete for 10 wk after soybean unifoliate expansion (8). Similar work has been conducted with waterhemp populations in corn where season-long interference at densities of 362 or more waterhemp plants/sq m reduced corn yield up to 36% (4). In addition, if high densities of waterhemp were not controlled by the time corn reached 6 inches in height, corn yield reductions of up to 15% occurred (4). A 10% corn yield loss was observed when lower waterhemp densities of 35 to 82 plants/sq m were allowed to compete season long (4). Steckel and Sprague found that season-long waterhemp interference reduced corn yield by 11 to 74% over three growing seasons (31).

The most common method of weed removal in agronomic cropping systems is the application of single or mixture of selective herbicides. However, sole dependency on any one herbicide and/or herbicide-resistant crop technology has led to the selection of Palmer amaranth and waterhemp biotypes with resistance to herbicides that once effectively controlled these species (11). One of the most effective ways to reduce the selection of herbicide-resistant biotypes is by implementing crop and herbicide mode-of-action rotation with cultural practices over multiple years (13,28,35). There are three soybean systems currently available that could be integrated into a crop rotation over multiple years; these include glyphosate-resistant (Roundup Ready; Monsanto, St. Louis, MO), glufosinate-resistant (Liberty Link; Bayer CropScience, Research Triangle Park, NC), and nontransgenic, or conventional, soybean cultivars. Glyphosate-resistant soybean was commercially introduced in the United States in 1996. After their introduction, glyphosate-resistant soybean was rapidly adopted. In 1997, 17% of the soybean acreage in the United States was planted with glyphosate-resistant varieties; by 2012, the adoption of herbicide-resistant soybean in the United States had increased to 93%, of which the vast majority were glyphosate-resistant varieties (33). The increase in glyphosate-resistant soybean acreage has been attributed to the fact that glyphosate is an economical and convenient broad spectrum herbicide when compared to other herbicide options (6). Glufosinate-resistant soybean was first introduced in 1999 on a limited basis (34) and was then fully commercialized and released in 2009 (7).

Few studies have been conducted to evaluate the economics of herbicide-resistant and conventional soybean systems. Reddy and Whiting (25) evaluated the economics of a glyphosate-resistant soybean system in which glyphosate was used as the only herbicide for weed control compared to a sulfonlurea-resistant and conventional soybean system (25). Results from this study showed that the net returns from the glyphosate-resistant system was US$165/acre as compared to $110/acre and $128/acre in the sulfonlurea-resistant and conventional soybean systems, respectively. However, the cost of glyphosate-resistant soybean seed has increased in recent years and a more recent comparison of net returns across the different herbicide programs and soybean systems is needed.

In addition, few studies have compared weed management systems in glyphosate-resistant, glufosinate-resistant, and conventional soybean cropping systems (12,34). In one study, sequential applications of glufosinate improved control over single applications while in comparison, sequential applications of glyphosate generally provided no advantages over single applications (12,34). Several conventional soybean herbicide programs can be comparable to transgenic programs; however, conventional herbicides must be applied to small weeds (0.5 to 3 inches in height) to obtain acceptable control (12). Similar to conventional herbicides, it is necessary to apply glufosinate when weeds are small (2 to 3 inches in height) to obtain the best control of a general weed population (12). Overall, effective weed control with most herbicides including glyphosate is dependent on weed size at the time of application.

The objectives of this study were (i) to determine which herbicide program provides the most effective, season-long weed control of Palmer amaranth or waterhemp and maximize soybean seed yield in conventional, glyphosate-resistant, and glufosinate-resistant soybean systems and (ii) to determine which soybean system and herbicide program provides the greatest net income to soybean producers.

Herbicide Programs for the Management of Waterhemp and Palmer Amaranth in Soybean Systems

Field experiments were conducted at two locations during the summers of 2009 and 2010. The sites were located in Callaway County in central Missouri (38°39'57.02"
Table 1. Specific herbicide treatments and programs evaluated in the experiments.

<table>
<thead>
<tr>
<th>Herbicide program*</th>
<th>Conventional</th>
<th>Glyphosate resistant</th>
<th>Glufosinate resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE-only</td>
<td>0.18 sulfentrazone + 0.03 cloransulam + 0.77 S-metolachlor + 0.17 fomesafen</td>
<td>0.18 sulfentrazone + 0.03 cloransulam + 0.77 S-metolachlor + 0.17 fomesafen</td>
<td></td>
</tr>
<tr>
<td>PRE fb POST</td>
<td>0.62 S-metolachlor + 0.13 fomesafen fb 0.20 lactofen + 0.07 clethodim</td>
<td>0.62 S-metolachlor + 0.13 fomesafen fb 0.77 glyphosate</td>
<td></td>
</tr>
<tr>
<td>2-pass POST</td>
<td>0.16 or 0.20 lactofen + 0.07 clethodim</td>
<td>0.77 glyphosate fb 0.77 glyphosate</td>
<td></td>
</tr>
<tr>
<td>1-pass POST W/Res</td>
<td>0.20 lactofen + 0.07 clethodim 0.71 S-metolachlor + 0.16 fomesafen</td>
<td>0.77 glyphosate 0.40 glufosinate</td>
<td></td>
</tr>
<tr>
<td>1-pass POST</td>
<td>0.20 lactofen + 0.08 clethodim + 0.03 flumiclorac</td>
<td>1.55 glyphosate 0.66 glufosinate</td>
<td></td>
</tr>
</tbody>
</table>

*PRE-only, preemergence only application; PRE fb POST, preemergence followed by a postemergence application; 1-pass POST W/Res, one-pass postemergence application with a residual herbicide; 1-pass POST, one-pass postemergence application.

All rates in pounds a.i. per acre except for glyphosate, which is presented in pounds acid equivalent per acre. Surfactant or adjuvant used at labeled rate.

N, 91°52′28.51″ W) (“waterhemp site”) and at the Delta Research Center in Pemiscot County in southeast Missouri (36°23′26.49″ N, 89°36′31″ W) (“Palmer amaranth site”). Both sites were selected based on the presence of dense infestations of waterhemp (184 plants/sq m) at the central location and Palmer amaranth (199 plants/sq m) at the southeast location. The waterhemp population at the Callaway County site contained a low percentage of individuals that exhibited resistance to glyphosate and acetolactate synthase (ALS) herbicides while the Palmer amaranth population at the Pemiscot County site was susceptible to glyphosate and ALS herbicides. The soil type at the waterhemp site was a Hodge fine sand (loamy substratum, Mixed, mesic Typic Udipsamments) and contained 1.4% organic matter with a pH of 6.8. The soil type at the southeast location was a Dundee silt (loam Fine-silty, mixed, active, thermic Typic Endoaqualfs) and contained 1.3% organic matter with a pH of 5.6. At both locations, ‘Schillerling 388TC’ conventional, ‘Asgrow AG3803’ glyphosate-resistant, and ‘MBS Genetics ML3963N’ glufosinate-resistant soybean were planted into a conventionally tilled seedbed in rows spaced 30 inches apart at a seeding rate of 160,000 seeds/acre. Planting dates were on 12 May 2009 and 6 May 2010 at the waterhemp site and 20 May 2009 and 25 May 2010 at the Palmer amaranth site. In all experiments, the experimental design consisted of randomized complete block design with 18 treatments. All plots were 10 by 30 ft and replicated six times.

The herbicide programs evaluated in these experiments consisted of those commonly used to control susceptible and resistant populations of glyphosate-resistant Palmer amaranth and waterhemp. The herbicide programs included a preemergence only application (PRE-only), a preemergence followed by a postemergence application (PRE fb POST), a two-pass postemergence application (2-pass POST), a one-pass postemergence application with a residual herbicide (1-pass POST W/Res), and a one-pass postemergence application (1-pass POST). For each soybean system, a nontreated control was included for comparison. The POST applications in the 1-pass POST herbicide program were made when waterhemp and Palmer amaranth averaged 10 inches in height while POST applications in the remaining herbicide programs were made when the average height of waterhemp or Palmer amaranth was between 4 and 6 inches. Individual treatments within each soybean system are listed in Table 1, herbicide application dates are listed in Table 2, and monthly rainfall and average monthly temperatures are listed in Table 3. All herbicide applications were made with a CO2 backpack sprayer set to deliver 15 gal/acre with XR8002 flat fan nozzles at a speed of 3 mi/h. To prevent herbicide drift across the different soybean systems, 3 by 7 ft tarp were held by two people walking on each side of the spray boom during herbicide application.

Treatment Evaluation and Data Collection

Visual waterhemp or Palmer amaranth control and soybean injury were evaluated in response to each herbicide treatment. Evaluations were taken at 2-wk intervals up to 10 wk after soybean emergence. Ratings were based on a scale of 0 to 100%, with 0 equal to the plant vigor and ground cover observed in the nontreated control or no soybean injury and 100 equal to complete weed control or complete soybean death (Table 4). Soybean...
crop management was harvested from the center two rows in each plot with a small plot combine and yields were adjusted to 13% moisture content.

**Economic and Statistical Analysis**

The net return in response to each herbicide program and soybean system was calculated by subtracting the estimated treatment costs from gross income. Gross income was determined in dollars per acre by multiplying the soybean yield from each treatment by an average soybean price of $11.30/bu. This is the average soybean price for the 2010/2011 crop year provided by the Food and Agricultural Research Policy Institute (3). The cost of each herbicide treatment was calculated from the 2009 wholesale price sheet of herbicides and adjuvants provided by a major agricultural retailer in the Midwest and also included technology fees and seed costs associated with each soybean variety. A custom application fee of $5/acre was also included for each herbicide application made within an herbicide program (23).

A partial budget was conducted to evaluate specific changes in the producers operation including soybean systems and herbicide programs. The partial budget system analyzes alternatives to an industry standard and determines if a change from the industry standard will change the net income. Therefore, a partial budget compares the positive and negative effects of the proposed change (alternative) on net income. In this type of budgeting system, only the affected costs and revenues are included in the analysis and nonaffected operating costs are presumed as fixed costs and are not included in the final net return. In this study, glyphosate-resistant soybean with a 2-pass POST glyphosate program were used as the industry standard. This standard was selected based on USDA-Economic Research Service data, which indicates 93% of all soybean planted in 2009/2010 were genetically modified and the total number of times a field was treated with a herbicide was 2.1 (33).

Visual weed control, soybean injury, and soybean yield data were subjected to analysis of variance using SAS PROC MIXED (SAS Institute Inc., Cary, NC). Fixed effects included site, year, soybean system, and herbicide program, and replication within year was used as the random effect. Data was combined over years but not site due to different weed species responses; site means are presented separately. Means were separated using Fisher’s protected LSD at \( P \leq 0.05 \). Data were subjected to a square-root transformation. However, nontransformed means are presented as data transformation did not improve the model.

**Soybean Injury in Response to Various Herbicide Programs in Three Soybean Systems**

Collectively, across all soybean systems and herbicide programs, the greatest level of soybean injury was observed in the conventional soybean system where at least one POST herbicide application occurred (Table 4). Soybean injury 6
wk after emergence (WAE) ranged from 7 to 25% with all conventional herbicide programs that contained a POST treatment and was greater than the injury observed in the glufosinate- and glyphosate-resistant soybean systems in almost every instance (Table 4). The soybean injury observed in response to all POST herbicide programs within the conventional soybean system is consistent with previous research, as the soil residual with many conventional POST herbicide products will lead to elevated crop injury (23,29). Although glyphosate- and glufosinate-resistant soybean has high levels of tolerance to glyphosate and glufosinate, respectively, Nolte and Young also reported that the inclusion of a residual herbicide with POST herbicide applications in these systems could result in a higher level of soybean injury with some varieties (23). Soon after application, higher levels of soybean injury were observed in response to the 1-pass POST W/Res programs but in all instances the soybean recovered within a 2-wk time period (data not shown). Less than 15% soybean injury was reported across all other soybean systems and herbicide treatments evaluated at both locations. Preemergence followed by a postemergence application and 2-pass POST herbicide programs in both the glyphosate- and glufosinate-resistant soybean systems resulted in the lowest levels of visual soybean injury at the waterhemp site while few trends were observed at the Palmer amaranth site (Table 4). The differences observed between sites may partially be explained by variation in soil type or environmental conditions (Table 3).

### Waterhemp and Palmer Amaranth Control with Herbicide Programs and Soybean Systems

Across both locations, herbicide programs that included preemergence (PRE) herbicide applications generally provided highest levels of waterhemp and Palmer amaranth control 10 WAE (Table 5). The exception to this occurred with the PRE fb POST program at the Palmer amaranth site, which provided 18 to 31% lower levels of weed control (Table 5).

At the waterhemp site, other herbicide programs such as the 2-pass POST program with glufosinate-resistant soybean provided similar waterhemp control as herbicide programs that included PRE-only and PRE fb POST for all three soybean systems 10 WAE (Table 5). Additionally, Palmer amaranth control with the 2-pass POST program for either glufosinate-resistant or glyphosate-resistant soybean at the Palmer amaranth site was similar to the Palmer amaranth control observed in the PRE-only herbicide program. Greater control of weed species such as waterhemp with sequential applications of glufosinate or glyphosate compared to single applications has also been reported in previous research (2,15,23,36).

<table>
<thead>
<tr>
<th>Location</th>
<th>Soybean system</th>
<th>Herbicide program</th>
<th>Waterhemp percentage injury</th>
<th>Palmer amaranth percentage injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>PRE-only</td>
<td>Waterhemp</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>PRE fb POST</td>
<td></td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>2-pass POST</td>
<td></td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>1-pass POST W/Res</td>
<td></td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1-pass POST</td>
<td></td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Glufosinate resistant</td>
<td>PRE-only</td>
<td>Waterhemp</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PRE fb POST</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2-pass POST</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1-pass POST W/Res</td>
<td></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1-pass POST</td>
<td></td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Glyphosate resistant</td>
<td>PRE-only</td>
<td>Waterhemp</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>PRE fb POST</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2-pass POST</td>
<td></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1-pass POST W/Res</td>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1-pass POST</td>
<td></td>
<td>6</td>
<td>14</td>
</tr>
</tbody>
</table>

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30-yr average (1980–2009) obtained from National Climatic Data Center (22).

### Table 3. Monthly rainfall (inches) and average monthly temperatures (°F) from May through October in 2009 and 2010 in comparison to the 30-yr average at the central (waterhemp) and southeast (Palmer amaranth) research locations in Missouri.

### Table 4. Crop injury (6 wk after emergence) as influenced by herbicide programs in conventional, glyphosate-resistant, and glufosinate-resistant soybean at two locations (2009–2010).

30-yr average (1980–2009) obtained from National Climatic Data Center (22).

At the waterhemp site, other herbicide programs such as the 2-pass POST program with glufosinate-resistant soybean provided similar waterhemp control as herbicide programs that included PRE-only and PRE fb POST for all three soybean systems 10 WAE (Table 5). Additionally, Palmer amaranth control with the 2-pass POST program for either glufosinate-resistant or glyphosate-resistant soybean at the Palmer amaranth site was similar to the Palmer amaranth control observed in the PRE-only herbicide program. Greater control of weed species such as waterhemp with sequential applications of glufosinate or glyphosate compared to single applications has also been reported in previous research (2,15,23,36).
Within each soybean system at the waterhemp site, an 8 to 10% lower level of waterhemp control was observed with the 1-pass POST program and these results are consistent with previous research (23) (Table 5). At the Palmer amaranth site, the 1-pass POST and 1-pass POST W/Res programs provided similar Palmer amaranth control in the glufosinate-resistant soybean system. Palmer amaranth control in 1-pass POST and 2-pass POST conventional soybean programs resulted in poor (<30%) control (Table 5). With the exception of conventional soybean at the Palmer amaranth site, the 1-pass POST herbicide program at both research locations provided the lowest levels of weed control for each soybean system (Table 5). This data corresponds with previous research suggesting the most successful weed control is achieved when smaller weeds (4 inch or less) are targeted with herbicides (12). Furthermore, conventional soybean systems that included a POST herbicide provided less than 70% Palmer amaranth control (Table 5). The results from this research indicate that Palmer amaranth may be particularly difficult to control in conventional soybean systems.

It is also important to note that neither of these research locations contained glyphosate-resistant populations of waterhemp or Palmer amaranth. No resistance was reported at the Palmer amaranth site, and an extremely low level of glyphosate resistance had been observed at the waterhemp site. The most notable weed with glyphosate resistance in Missouri is waterhemp (26). Therefore, the presence of glyphosate-resistant weed biotypes at these research locations would have influenced the results of the 2-pass POST program considerably. The absence of glyphosate resistant weed biotypes is specifically noted at the Palmer amaranth site in the glyphosate-resistant soybean system as all herbicide programs provided similar levels (>82%) of Palmer amaranth control (Table 5).

### Soybean Yield Response to Herbicide Programs and Soybean Systems

Averaged across all herbicide programs and research locations, glufosinate-resistant soybean yielded higher (40 bu/acre) than glyphosate-resistant (38 bu/acre) and conventional soybean (30 bu/acre), respectively ($P = 0.001$). Within each soybean system at the waterhemp site, all herbicide programs resulted in similar soybean yields. The differences in soybean yield observed in this research are likely due a combination of factors, including the genetic differences in the soybean varieties, differences in the herbicide programs evaluated, and the environmental conditions at each location (Table 3).

At the Palmer amaranth site, conventional soybean that included a PRE herbicide in the program yielded highest and were different (≥6 bu/acre) from the POST-only herbicide programs. In fact, POST-only programs in conventional soybean resulted in soybean yields similar to the nontreated control at the Palmer amaranth site.

Regardless of the location, the lower yields in the conventional system are likely due to the poor control of waterhemp or Palmer amaranth due to ineffective herbicide programs (Table 5). In the glufosinate-resistant soybean system at the Palmer amaranth site, soybean yields were similar for all herbicide programs except the 1-pass POST herbicide program, which resulted in lower (24 bu/acre) yields. This response was also likely related to the poor control of Palmer amaranth provided by this herbicide program in glufosinate-resistant soybean (Table 5).

As reported previously, if waterhemp or Palmer amaranth density and biomass increase throughout the growing season, soybean yield will be reduced (4,16). Glyphosate-resistant soybean yields were similar at the Palmer amaranth site in response to PRE-only, PRE fb POST, 1-pass POST W/Res, and 1-pass POST herbicide programs (Table 6). However, glyphosate-resistant soybean yields were highest with the 2-pass POST herbicide program at the Palmer amaranth site, and the PRE-only herbicide program was the only other herbicide program that resulted in similar soybean yield (Table 6).

Across soybean systems the nontreated control provided similar soybean yields, and in the case of the glufosinate-resistant and glyphosate-resistant soybean systems, soybean yields in the nontreated control were

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Table 5. Late season waterhemp or Palmer amaranth control (10 wk after emergence) as influenced by herbicide programs in conventional, glyphosate-resistant, and glufosinate-resistant soybean at two locations (2009–2010).

<table>
<thead>
<tr>
<th>Soybean system</th>
<th>Herbicide program</th>
<th>Location</th>
<th>Waterhemp</th>
<th>Palmer amaranth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE-only</td>
<td></td>
<td></td>
<td>99</td>
<td>86</td>
</tr>
<tr>
<td>PRE fb POST</td>
<td></td>
<td></td>
<td>92</td>
<td>68</td>
</tr>
<tr>
<td>2-pass POST</td>
<td></td>
<td></td>
<td>89</td>
<td>26</td>
</tr>
<tr>
<td>1-pass POST W/Res</td>
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<td>80</td>
<td>18</td>
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<td>1-pass POST</td>
<td></td>
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<td>72</td>
<td>30</td>
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<td>Glufosinate resistant</td>
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<td>84</td>
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<td>PRE fb POST</td>
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<td>86</td>
</tr>
<tr>
<td>1-pass POST</td>
<td></td>
<td></td>
<td>64</td>
<td>85</td>
</tr>
</tbody>
</table>

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(A table showing late season waterhemp or Palmer amaranth control with corresponding locations for conventional and glufosinate-resistant soybean systems, indicating the percentage control for waterhemp and Palmer amaranth across different herbicide programs.)

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* PRE-only, preemergence only application; PRE fb POST, preemergence followed by a postemergence application; 2-pass POST, two-pass postemergence application; 1-pass POST W/Res, one-pass postemergence application with a residual herbicide; 1-pass POST, one-pass postemergence application.

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* Percent control values are an average of all 2012 and 2013 locations (range: 16.5 to 91.5% for waterhemp and 0% to 100% for Palmer amaranth). LSD (0.05) values are not given for Palmer amaranth control because no significant differences were detected (Table 5).
lower than all other herbicide programs. When averaged across soybean systems and locations, PRE-only herbicide programs provided the greatest soybean yield (37.7 bu/acre) followed by 2-pass POST (36.7 bu/acre), PRE fb POST (36.5 bu/acre), 1-pass POST W/Res (35.7 bu/acre), and 1-pass POST (33.7 bu/acre) ($P = 0.001$).

### Net Returns in Response to Various Herbicide Programs in Three Soybean Systems

The positive or negative alternative treatment differences calculated from the industry standard net return is reported for each soybean system and herbicide program in Table 7. The net return of the industry standard was $415.70 at the waterhemp site (Table 7). At the waterhemp site, the partial budget analysis net return gain or loss ranged from $-121.75 in the 2-pass POST conventional soybean to $74.33 in the 1-pass POST glufosinate-resistant soybean when compared to the industry standard net income (Table 7). At the waterhemp site, all conventional soybean herbicide programs provided a negative net return, which is likely due to lower grain yield compared to the other soybean systems (Table 6) and/or reduced waterhemp control (Table 5). Positive net gains were observed in response to all glufosinate-resistant soybean system herbicide programs at the waterhemp site. In addition, the PRE-only herbicide program was the only program that resulted in a negative net return in the glyphosate-resistant soybean system. Across these two soybean systems, greater net return was observed in the glufosinate-resistant soybean system as compared to the glyphosate-resistant system. This can be explained by the fact that glufosinate-resistant soybean seed cost less than glyphosate-resistant seed and that glufosinate-resistant soybean yielded higher than glyphosate-resistant soybean (Table 6).

The net return of the industry standard was $325.31/acre at the Palmer amaranth site (Table 7). At the Palmer amaranth site, the partial budget analysis resulted in a negative net return regardless of the soybean system or herbicide program when compared to the 2-pass POST program.
Glyphosate-resistant soybean industry standard. Net loss ranged from ~$14.20 in the 2-pass POST glufosinate-resistant soybean system to ~$200.85 in the 2-pass POST conventional soybean system (Table 7). It is important to note that this occurred at a site without glyphosate-resistant Palmer amaranth and this would not likely occur in a location where glyphosate-resistant Palmer amaranth is present. The net decrease observed across all soybean systems and herbicide programs at the Palmer amaranth site can be partially attributed to the differences in soil composition, weed control (Table 5), and yield as compared to the industry standard at the waterhemp site (Table 6). Soil texture at the waterhemp site was coarse and sandier compared with the Palmer amaranth site, which had a higher clay content; therefore, the high clay texture at the Palmer amaranth site may have a greater potential for herbicide sorption leading to decreased herbicide activity (5). Additionally, the Palmer amaranth site received less rainfall during the 2010 growing season (Table 3), which contributed to lower soybean yields in both years compared to the waterhemp site (Table 6). Rainfall is essential for not only influencing soybean yield but also herbicide activity. Drought-stressed weeds are more difficult to control with POST herbicide applications because of reduced herbicide adsorption and low physiological activity (19), and drought stress occurred at the Palmer amaranth site during 2010 (Table 3).

Summary

The results from this research indicates that the greatest crop injury, poorest control of waterhemp or Palmer amaranth, and lowest crop yields occurred in conventional soybean where a POST-only herbicide program was used. In addition to previous literature (1), this study also suggests that Palmer amaranth may be a more competitive species than waterhemp and is more difficult to control in a conventional soybean system. In general, herbicide programs that contained preemergence herbicides provided the highest level of waterhemp control, and similar Palmer amaranth control was observed in both preemergence programs and the 2-pass POST program for glyphosate- and glufosinate-resistant soybean systems. The results from these experiments also indicate that higher net returns can occur in glufosinate-resistant soybean systems, primarily due to lower seed costs and acceptable levels of waterhemp or Palmer amaranth control with certain herbicide programs. Evaluating differences between herbicide, seed, and other production costs while simultaneously determining weed control and yield responses enables producers to develop a partial budget. However, in this research net return differences were separated by weed control and soybean yields more than treatment costs. Regardless of the research results, incorporation of herbicide programs that use two or more multiple modes of action may reduce the shift to herbicide-resistant weed biotypes. Furthermore, weed control and soybean yield may have been significantly altered if resistant weeds were present at the research sites.

Literature Cited


21. Murphy, S.D., Y. Yankubu, S.F. Weise, and C.J. Swanton. 1996. Effect on planting patterns and inter-row cultivation on competition quantity, weed control and soybean yield may have been significantly altered if resistant weeds were present at the research sites.
between corn (Zea mays) and late emerging weeds. Weed Sci. 44:865–870.


