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Comparison of Herbicide Tactics to Minimize Species Shifts and Selection Pressure in Glyphosate-Resistant Soybean

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There are significant concerns over the long- and short-term implications of continuous glyphosate use and potential problems associated with weed species shifts and the development of glyphosate-resistant weed species. Field research was conducted to determine the effect of herbicide treatment and application timing on weed control in glyphosate-resistant soybean. Ten herbicide treatments were evaluated that represented a range of PPI, PRE, and POST-only application timings. All herbicide treatments included a reduced rate of glyphosate applied POST. PRE herbicides with residual properties followed by (fb) glyphosate POST provides more effective control of broadleaf weed species than POST-only treatments. There was no difference in soybean yield between PRE fb POST and POST-only treatments in 2008. Conversely, PRE fb POST herbicide treatments resulted in greater yield than POST-only treatments in 2009. Using PRE fb POST herbicide tactics improves weed control and reduces the risk for crop yield loss when dealing with both early- and late-emerging annual broadleaf weed species across variable cropping environments.
Nomenclature: Glyphosate; common lambsquarters, *Chenopodium album* L. CHEAL; common waterhemp, *Amaranthus rudis* Sauer AMATA; giant ragweed, *Ambrosia trifida* L., AMBTR.
Key words: Preemergence herbicides, postemergence herbicides, herbicide resistance.

Existen preocupaciones importantes sobre las implicaciones a largo y corto plazo del uso continuo de glifosato y los problemas potenciales asociados con los cambios en las comunidades de malezas y el desarrollo de especies de malezas resistentes al glifosato. Se realizaron investigaciones de campo para determinar el efecto de los tratamientos y momentos de aplicación de herbicidas en el control de malezas en soya resistente al glifosato. Se evaluaron diez tratamientos de herbicida que representaron una variedad de momentos de aplicación PPI, PRE y POST-solamente. Todos los tratamientos incluyeron una dosis reducida de glifosato aplicado POST. Los herbicidas PRE con propiedades residuales seguidos de glifosato POST proporcionaron un control más eficaz de malezas de hoja ancha que los tratamientos solamente POST. No hubo ninguna diferencia en el rendimiento de la soya entre los tratamientos PRE seguidos por POST y los solamente POST en 2008. En cambio, en 2009, los tratamientos PRE seguidos por (fb) POST tuvieron como resultado mayor rendimiento que los tratamientos solamente POST. El uso de tácticas de que incluyan herbicidas PRE seguidos por POST mejora el control de malezas y reduce el riesgo de pérdidas en el rendimiento del cultivo cuando se trata con malezas anuales de hoja ancha, tempranas y tardías, en ambientes variables de cultivo.

Herbicide use patterns have changed dramatically over the past several years due in large part to the development of glyphosate-resistant crops (Young 2006). Herbicide strategies that involved tank mixtures, incorporating several modes of actions, and the use of residual herbicides plus interrow cultivation have been overtaken by single or multiple POST applications of glyphosate (Givens et al. 2009; Johnson et al. 2009). Although herbicide use patterns are now beginning to incorporate more diversified approaches, there remains a concern over the long- and short-term implications of continuous glyphosate use and potential problems associated with weed species shifts and the development of glyphosate-resistant weed species (Dill et al. 2008; Johnson et al. 2009).

Johnson et al. (2009) suggest that as a result of increasing glyphosate use, most of the problematic weeds associated with arable cropping systems have shifted away from annual grass and perennial species to annual broadleaf species. This is especially evident in the upper Midwest where giant and common ragweed (*Ambrosia artemisiifolia* L. AMBEL), common waterhemp, and common lambsquarters are now among the dominant weed species in glyphosate-resistant cropping systems. Recent reports indicate that 11 weed species are now resistant to glyphosate in the United States (Heap 2011). Of those, glyphosate-resistant giant ragweed populations have been reported in eight states, while seven states have reported glyphosate-resistant common waterhemp populations. Glyphosate-tolerant biotypes of common lambsquarters have also been identified in field situations (Westhoven et al. 2008). To address these concerns, many are recommending herbicide use patterns that were in place before glyphosate; e.g., use of other herbicides with a different mode of action and/or the use of herbicides with residual properties to minimize weed species shifts and selection pressure in glyphosate-resistant cropping systems (Dill et al. 2008; Gustafson 2008).

Glyphosate is an effective postemergence herbicide that has been shown to control a broad spectrum of weed species, even when applied at below-label rates. Corrigan and Harvey (2000) showed that a reduced rate of glyphosate provided acceptable season-long weed control in no-till drilled glyphosate-resistant

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soybean [*Glycine max* (L.) Merr.]. However, they acknowledged that the use of a preplant residual herbicide may be required to reduce early-season weed competition if the glyphosate application is delayed by adverse weather. Timing of application is an important consideration when using glyphosate (Hilgenfeld et al. 2004). In a study to determine the critical time of weed removal in glyphosate-resistant soybeans, Mulugeta and Boerboom (2000) found that a single application of glyphosate prevented yield loss in narrow-row soybean under favorable conditions but that application timing becomes more important in wide-row systems in which early-season weed control is necessary. The importance of proper application timing coupled with concerns related to the development of glyphosate-resistant weeds has caused many to reconsider weed management strategies in glyphosate-resistant cropping systems.

The addition of PRE and/or POST herbicides to a glyphosate-based weed management system may enhance weed control by adding residual weed control. Legleiter et al. (2009) demonstrated that the addition of a PRE herbicide in a glyphosate-based weed management strategy improved weed control of glyphosate-resistant waterhemp, reduced the amount of seed produced, and provided the highest soybean yields and net income. Knezevic et al. (2009) evaluated the performance of PRE herbicides as well as various POST glyphosate tank-mixes across three application timings in Nebraska. They showed that mixing glyphosate with other POST herbicides or utilizing PRE or PPI herbicides helped control most problem weeds in glyphosate-resistant soybean. Gonzini et al. (1999) also noted that the use of a tank-mix partner or a PRE herbicide fb glyphosate improved weed control compared with a single application of glyphosate. The use of PRE herbicides can also allow for flexibility in application timing when using glyphosate (Grichar 2006). VanGessel et al. (2000) noted that for optimum weed control in glyphosate-resistant cropping systems, the window of application for glyphosate alone was between the one- and three-trifoliate leaf stages, approximately 18 to 28 d after planting (DAP). However, if glyphosate was tank-mixed with residual herbicides, the window of application of glyphosate was extended to approximately 32 DAP. Ellis and Griffin (2002) noted that soil-applied herbicides used in their study extended the time of glyphosate application from 3 to 7 d, depending on herbicide and year applied.

The objective of this study is to determine the effect of herbicide treatment and application timing on weed control in glyphosate-resistant soybean.

Materials and Methods

Field research was conducted in 2008 and 2009 near Rochester, MN. The soil was a Lawler loam (mixed, superactive, mesic Aquic Hapludoll) with pH of 6.9 and 2.3% organic matter. Dairyland 'DSR 1302' and Asgrow 'AG2108' glyphosate-resistant soybeans were planted into a conventionally tilled seedbed on May 23, 2008, and May 19, 2009, respectively, at a rate of 370,000 seeds ha^{-1} in 76-cm rows. The experimental design was a randomized complete block with four replications. Individual plots measured 6 by 9 m. Fertilizer was applied according to soil test recommendations. Soybean grain was machine harvested in 2008 and 2009 from the two center rows of each plot. Grain mass and moisture was recorded for each plot and grain yields were standardized by correcting grain moisture to 13%.

Table 1. Herbicide application dates and soybean and weed characteristics at time of POST herbicide application in 2008 and 2009.

	2008	2009
Application date of PPI and PRE herbicides	May 23	May 19
Application date of POST herbicides	June 30	June 19
Soybean		
Stage	V2	V1
Height (cm)	20.3	7.6
Giant ragweed		
Density (no. m^{-2})	43	80
Height (cm)	20.3	22.6
Common waterhemp		
Density (no. m^{-2})	830	92
Height (cm)	4.8	3.5
Common lambsquarters		
Density (no. m^{-2})	40	28
Height (cm)	5.3	4.6

Ten herbicide treatments were evaluated that represented a range of PPI, PRE, and POST-only treatments. Pendimethalin represented the PPI treatment. Herbicides representing PRE treatments included flumioxazin and prepackaged mixtures of flumioxazin + cloransulam (Gangster herbicide, Valent Corporation, Walnut Creek, CA), sulfentrazone + imazethapyr (Authority Assist herbicide, FMC Corporation, Philadelphia, PA), sulfentrazone + cloransulam (Sonic herbicide, Dow AgroSciences, Indianapolis, IN), metolachlor + fomesafen (Prefix herbicide, Syngenta Crop Protection, Greensboro, NC), and chlorimuron + flumioxazin + thifensulfuron (Enlite herbicide, du Pont de Nemours and Company, Wilmington, DE). POST-only treatments included fluthiacet, cloransulam, thifensulfuron, imazethapyr, lactofen, fomesafen, and chlorimuron + thifensulfuron (Synchrony herbicide, du Pont de Nemours and Company). All herbicide treatments included glyphosate applied POST (either alone following the PPI or PRE or in tank mix with POST-only treatments) at a rate of 0.42 kg ae ha^{-1} plus 0.25% (v/v) nonionic surfactant and 2.2 kg ha^{-1} ammonium sulfate (Table 1). Herbicide application rates are listed in Table 2. A 0.42 kg ae ha^{-1} rate of glyphosate was used to (1) simulate poor glyphosate performance such as a glyphosate-resistant weed population in which some but not all weeds would be removed and (2) to put more emphasis on the sequential or tank-mix partners for control of weeds that could potentially be glyphosate resistant. Previous studies have shown that a 0.40 kg ae ha^{-1} rate reduces the effectiveness of glyphosate, leaving more weeds in the field compared with using a 0.80 kg ae ha^{-1} rate (Westra et al. 2008). Herbicides were applied with a tractor-mounted sprayer calibrated to deliver 327 L ha^{-1} at 103 kPa using flat-fan nozzles.

Visual ratings of weed control were obtained at 0 and 28 d after POST herbicide application. Visual ratings were based on a scale of 0 (no control) to 100 (complete control). Statistical analysis of visual weed control ratings and soybean yield data were performed using Analytical Software (Statistix

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Table 2. Effect of PPI, PRE, and POST herbicide programs on giant ragweed and common waterhemp control in 2008 and 2009.

			Days after planting (d after POST herbicide application)							
			Giant ragweed				Common waterhemp			
			2008		2009		2008		2009	
Herbicide program[a]	Timing	Rate	26	61 (28)	27	62 (31)	26	61 (28)	27	62 (31)
		g ai ha^{-1}	%							
Pendimethalin	PPI	1,597	0 f[b]	75 gh	0 f	87 cde	71 b	87 cd	92 b	92 b
Flumioxazin	PRE	89	24 e	89 bc	26 e	93 ab	99 a	96 ab	80 c	97 a
Flumioxazin + cloransulam	PRE	89 + 29	94 a	97 a	85 b	86 cde	99 a	99 a	93 ab	97 a
Sulfentrazone + cloransulam	PRE	130 + 17	86 b	89 bc	89 a	94 ab	99 a	93 bc	96 a	98 a
Sulfentrazone + imazethapyr	PRE	347 + 70	72 d	88 bcd	80 c	90 bcd	99 a	97 ab	96 a	99 a
Metolachlor + fomesafen	PRE	1,065 + 233	80 c	97 a	77 c	97 a	99 a	97 ab	96 ab	98 a
Chlorimuron + flumioxazin + thifensulfuron	PRE	5.6 + 71 + 17	80 c	92 b	65 d	93 ab	99 a	99 a	96 ab	98 a
Fluthiacet	POST	3	0 f	76 gh	0 f	73 g	0 c	76 f	0 d	74 ef
Cloransulam	POST	18	0 f	84 cde	0 f	91 bc	0 c	77 f	0 d	87 c
Thifensulfuron	POST	16	0 f	74 h	0 f	80 efg	0 c	86 de	0 d	79 de
Imazethapyr	POST	70	0 f	73 h	0 f	91 bcd	0 c	81 ef	0 d	80 de
Lactofen	POST	105	0 f	83 def	0 f	84 def	0 c	87 cde	0 d	89 bc
Fomesafen	POST	197	0 f	83 def	0 f	87 cde	0 c	90 cd	0 d	88 c
Chlorimuron + thifensulfuron	POST	7	0 f	78 fgh	0 f	83 ef	0 c	81 ef	0 d	83 d
Glyphosate	POST	420	0 f	81 efg	0 f	78 fg	0 c	77 f	0 d	73 f
Contrast[c]										
PRE fb POST vs. POST only				**		*		**		**

[a] All herbicide treatments included glyphosate applied POST at a rate of 0.42 kg ae ha^{-1}.

[b] For each year, means within a column followed by the same letter are not significantly different according to Fisher's protected LSD test ($P < 0.10$).

[c] Does not include glyphosate only POST. Abbreviation: fb = followed by.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

9, Tallahassee, FL). Visual weed control ratings were transformed using arcsine of the square root prior to analysis. A significant year by treatment interaction was detected for each visual control rating date. Therefore, results are presented by year. Mean separation was based on Fisher's Protected LSD test ($P < 0.10$). Nontransformed data are presented with statistical interpretation based upon transformed data.

Results and Discussion

Giant Ragweed. In 2008, a PRE application of cloransulam plus either flumioxazin or sulfentrazone provided greater than 85% control of giant ragweed at 26 DAP (Table 2). Giant ragweed control was improved by the addition of a half-rate glyphosate POST to most of the PRE treatments. For example, flumioxazin PRE provided only 24% control of giant ragweed 26 DAP. When flumioxazin PRE was followed by a half-rate of glyphosate POST, giant ragweed control improved significantly and was greater than glyphosate alone. By 61 DAP (28 d after treatment), a PRE application of cloransulam + flumioxazin or metolachlor + fomesafen fb glyphosate POST provided 97% control of giant ragweed and was significantly higher than all other treatments. Giant ragweed control was improved in all of the PRE treatments by the addition of a half-rate of glyphosate; however, none of the POST-only treatments provided better control of giant ragweed than the POST glyphosate-alone treatment. As expected, pendimethalin PPI was ineffective on giant ragweed. However, control of giant ragweed with a POST application of glyphosate following pendimethalin was not different from glyphosate alone.

A 1 degree of freedom contrast analysis indicated that overall, PRE fb POST treatments resulted in greater giant ragweed control than POST-only treatments across all weed control evaluation dates in 2008 (Table 2). However, giant ragweed control was dependent on the herbicide treatment selected. To illustrate, the treatments that provided the greatest full-season weed control (PRE through 28 to 31 d after POST application) involved lactofen, fomesafen, and cloransulam—herbicides that have been shown to have activity on giant ragweed. This indicates that proper selection of PRE and POST herbicides is critical when managing for glyphosate-resistant giant ragweed populations.

In 2009, a PRE application of cloransulam + flumioxazin or sulfentrazone fb glyphosate POST resulted in 85% or greater control of giant ragweed at 27 DAP, same as in 2008 (Table 1). By 62 DAP, all PRE fb POST treatments and cloransulam, imazethapyr, and fomesafen POST provided greater giant ragweed control than the half-rate of glyphosate. As in 2008, pendimethalin PPI was ineffective on giant ragweed in 2009. There were small differences between pendimethalin PPI fb glyphosate POST and a single POST application of glyphosate at 62 DAP. Overall, our data suggests that application of a PRE herbicide provides better options for managing giant ragweed in glyphosate-tolerant soybeans. The residual properties of effective PRE herbicides

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Table 3. Effect of PPI, PRE, and POST herbicide programs on common lambsquarters control in 2008 and 2009.

Herbicide program[a]	Timing	Rate	Days after planting (d after POST herbicide application)			
			2008		2009	
			26	61 (28)	27	62 (31)
		g ai ha^{-1}	%			
Pendimethalin	PPI	1,597	65 c [b]	93 cd	88 b	93 c
Flumioxazin	PRE	89	99 a	98 a	53 d	92 cd
Flumioxazin + cloransulam	PRE	89 + 29	99 a	99 a	99 a	85 de
Sulfentrazone + cloransulam	PRE	130 + 17	99 a	97 ab	99 a	98 ab
Sulfentrazone + imazethapyr	PRE	347 + 70	99 a	98 a	97 a	99 a
Metolachlor + fomesafen	PRE	1,065 + 233	88 b	96 bc	75 c	79 ef
Chlorimuron + flumioxazin + thifensulfuron	PRE	5.6 + 71 + 17	99 a	99 a	99 a	96 abc
Fluthiacet	POST	3	0 d	88 ef	0 e	85 de
Cloransulam	POST	18	0 d	85 fg	0 e	90 cd
Thifensulfuron	POST	16	0 d	91 de	0 e	85 de
Imazethapyr	POST	70	0 d	86 fg	0 e	93 bc
Lactofen	POST	105	0 d	82 g	0 e	86 de
Fomesafen	POST	197	0 d	89 ef	0 e	76 f
Chlorimuron + thifensulfuron	POST	7	0 d	88 ef	0 e	91 cd
Glyphosate	POST	420	0 d	87 efg	0 e	86 de
Contrast[c]						
PRE fb POST vs. POST only				**		ns

[a] All herbicide treatments included glyphosate applied POST at a rate of 0.42 kg ae ha^{-1}.

[b] For each year, means within a column followed by the same letter are not significantly different according to Fisher's protected LSD test ($P < 0.10$).

[c] Does not include glyphosate only POST. Abbreviations: fb = followed by; ns = not significant.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

effectively controlled giant ragweed populations throughout the season.

Common Waterhemp. In 2008, common waterhemp control was greater than 90% for all PRE and PRE fb POST treatments at 26 and 61 DAP, respectively (Table 2). By 61 DAP (28 d after POST application), all POST-only treatments achieved greater than 80% control of common waterhemp, except for fluthiacet + glyphosate, cloransulam + glyphosate, and glyphosate alone. Contrast analysis indicated the PRE fb POST herbicide treatments resulted in greater waterhemp control than POST-only treatments at all evaluation dates.

In 2009, common waterhemp control was greater than 90% for all PRE and PRE fb glyphosate POST treatments at 26 and 61 DAP, respectively, except for flumioxazin PRE at 27 DAP (Table 2). Although common waterhemp control was greater than 70% across all treatments by 61 and 62 DAP, PRE fb glyphosate POST application treatments resulted in greater common waterhemp control than POST-only treatments.

Common Lambsquarters. In 2008, all PRE fb POST herbicide treatments provided greater than 95% control of common lambsquarters across all weed control evaluation dates, except for metolachlor + fomesafen at 26 DAP (Table 3). At 61 DAP all PRE fb POST herbicide treatments, including the metholachlor + fomesafen PRE fb glyphosate POST treatment, provided greater than 95% control of common lambsquarters. Pendimethalin PPI provided 65% control of common lambsquarters at 26 DAP. At 61 DAP (28 d after POST application), all POST-only herbicide treatments resulted in greater than 80% control of lambsquarters. However, there was no difference between a single reduced-rate of glyphosate POST and other POST-only tank-mix treatments. Contrast analysis indicates PRE fb POST herbicide treatments resulted in greater lambsquarters control than POST-only herbicide treatments.

In 2009, most PRE fb POST herbicide treatments achieved greater than 97% control of common lambsquarters across all weed control evaluation dates (Table 3). The only exception was flumioxazin PRE at 27 DAP (53%) and metolachlor + fomesafen 27 DAP (75%) and metolachlor + fomesafen fb glyphosate (79%). A single POST application of the reduced-rate of glyphosate provided the same level of lambsquarters control as all of the POST-only treatments and some of the PRE fb POST treatments. Only cloransulam + sulfentrazone PRE fb glyphosate POST, sulfentrazone + imazethapyr PRE fb glyphosate POST, chlorimuron + flumioxazin + thifensulfuron PRE fb glyphosate POST, and imazethapyr + glyphosate POST resulted in greater control than a single POST application of glyphosate. Pendimethalin PPI provided 88% control of common lambsquarters at 27 DAP. At 62 DAP, pendimethalin PPI fb glyphosate POST provided greater control of common lambsquarters than a single application of glyphosate. Unlike 2008, there was no difference in lambsquarters control between PRE and POST-only herbicide treatments in 2009 at 62 DAP.

Soybean Yield. PRE fb glyphosate POST herbicide treatments that included flumioxazin, cloransulam + flumioxazin or sulfentrazone, sulfentrazone + imazethapyr, and chlorimuron + flumioxazin + thifensulfuron PRE fb glyphosate POST

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Table 4. Soybean yield as influenced by PPI, PRE, and POST herbicide programs in 2008 and 2009.

Herbicide program[a]	Timing	Rate	2008	2009
		g ai ha^{-1}	kg ha^{-1}	
Pendimethalin	PPI	1,597	1,008.9 cd[b]	2,044.7 def
Flumioxazin	PRE	89	1,412.5 a	2,091.8 cdef
Flumioxazin + cloransulam	PRE	89 + 29	1,318.3 ab	2,381.0 ab
Sulfentrazone + cloransulam	PRE	130 + 17	1,224.1 abc	2,475.2 a
Sulfentrazone + imazethapyr	PRE	347 + 70	1,385.6 a	2,259.9 abcd
Metolachlor + fomesafen	PRE	1,065 + 233	1,042.5 bcd	2,340.6 abc
Chlorimuron + flumioxazin + thifensulfuron	PRE	5.6 + 71 + 17	1,338.5 ab	2,327.2 abc
Fluthiacet	POST	3	766.8 de	1,668.0 gh
Cloransulam	POST	18	800.4 de	2,138.8 bcde
Thifensulfuron	POST	16	847.5 de	1,419.2 i
Imazethapyr	POST	70	679.3 e	1,930.4 ef
Lactofen	POST	105	786.9 de	1,547.0 hi
Fomesafen	POST	197	1,042.5 bcd	1,876.6 fg
Chlorimuron + thifensulfuron	POST	7	1,056.0 bcd	1,358.7 i
Glyphosate	POST	420	827.3 de	1,903.5 efg
Contrast[c]				
PRE fb POST vs. POST only			ns	*

[a] All herbicide treatments included glyphosate applied POST at a rate of 0.42 kg ae ha^{-1}

[b] For each year, means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test ($P = 0.10$)

[c] Does not include glyphosate only POST. Abbreviations: fb = followed by; ns = not significant.

* Significant at $P < 0.05$.

tended to produce higher soybean yield than other herbicide treatments in 2008 (Table 4). In 2009, with the exception of flumioxazin, these same herbicide treatments + metolachlor + fomesafen PRE resulted in the highest soybean yield. Contrast analysis indicates there was no difference in soybean yield between PRE fb POST and POST-only treatments in 2008. Conversely, PRE fb POST herbicide treatments resulted in greater yield than POST-only treatments in 2009.

POST application was based on weed size in this study (Table 1). However, POST applications were made at V2 in 2008 and V1 in 2009. Earlier application of POST herbicides in 2009 on highly competitive giant ragweed may have provided for less early-season weed competition and greater yields. Higher soybean yield in 2009 compared with 2008 was likely due to differences in rainfall throughout the growing season. In 2008, rainfall was well below normal from July through September, resulting in stress during flowering and pod set (data not shown). In 2009, rainfall was above normal and rainfall events were distributed more evenly throughout the growing season.

This study shows that residual herbicides applied PRE fb glyphosate POST provide greater control of difficult to control broadleaf weed species than a POST-only treatment. This is primarily driven by two early-emerging weed species, giant ragweed and common lambsquarters. These results are in agreement with previous research that indicates that PRE herbicides provide early weed suppression as well as extend the window of glyphosate application thereby protecting soybean yield (Legleiter et al. 2009). However, PRE herbicides that are effective on the target species provided season-long control of broadleaf weeds and did not necessarily respond to the addition of glyphosate POST. Conversely, PRE herbicides that are considered marginally effective did respond to a POST application of glyphosate. Using glyphosate in a tank mixture or sequentially with other herbicides does not necessarily improve weed control. The reduced rate of glyphosate failed to add additional control when tank mixed with POST herbicides that were not effective on target weed species.

Rainfall in 2008 was above normal during the first part of the season, especially during the period of PRE application in June. Greater control of giant ragweed using PRE strategies in 2008 compared with 2009 may have been due to less soil moisture availability at the time of application in 2009.

A sound planning strategy for minimizing the development of resistant weed biotypes should include the use of other modes of action in addition to glyphosate. However, our data show that care must be taken when choosing among herbicide treatments. For example, flumioxazin PRE may be a good choice for proactively managing common waterhemp resistance to glyphosate in glyphosate-resistant soybean. Although waterhemp control was excellent using this treatment, giant ragweed control was inconsistent, creating the potential for a shift in weed species composition as well as a possible scenario for selection of glyphosate-resistant biotypes of giant ragweed; whereas using flumioxazin + cloransulam would mitigate this scenario. Moreover, environmental conditions at the time of PRE or POST application affected efficacy between years. Stewart et al. (2010) showed that environmental conditions before and after a PRE or POST herbicide application influence herbicide efficacy and should be considered by growers when selecting herbicide treatments in a glyphosate-resistant cropping system. In a study of PRE herbicides in a glyphosate-resistant soybean system, Ellis and Griffin (2002) found that none of the herbicides provided complete control of all weeds. Using PRE fb POST herbicide tactics reduces efficacy risks when dealing with a diversity of annual broadleaf weeds and variable cropping environments.

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