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Weed Control in Soybean with Preemergence- and Postemergence-applied Herbicides

Maxwel C. Oliveira, Dave Feist, Steve Eskelsen, Jon E. Scott, and Stevan Z. Knezevic*

Abstract

In the past 20 years, weed control in soybean (*Glycine max*) was mainly based on postemergence (POST) applications of glyphosate, which resulted in glyphosate-resistant weeds. Herbicide-resistant weeds warrants evaluation of new strategies for effective control. Therefore, the objective of this study was to evaluate the performance of herbicides applied preemergence (PRE) and POST on 11 agronomic weeds in eastern Nebraska. The study was conducted in 2014 and 2015 in Concord, NE. The best PRE-applied treatments were metolachlor + imazethapyr, fomesafen + imazethapyr, flumioxazin + imazethapyr, and flumioxazin + metribuzin, which controlled broadleaf and grass weed species ≥90 and ≥80%, respectively. However, weed control with POST herbicides was more variable, ranging from 19 to 91%. The POST-applied fomesafen and fomesafen + imazethapyr controlled ivyleaf morningglory (*Ipomoea hederacea*), common lambsquarters (*Chenopodium album*), common waterhemp (*Amaranthus tuberculatus*), and redroot pigweed (*Amaranthus retroflexus*) ≥85%. Greater soybean yields were achieved with most PRE-applied herbicides and POST-applied fomesafen + imazethapyr only. Metolachlor + imazethapyr, metolachlor, and fomesafen applied PRE protected soybean yields better than when applied POST. Results suggested that PRE-applied herbicide mixtures of different sites of action are the base for controlling weeds and protecting soybean yields in eastern Nebraska.

The adoption of glyphosate-resistant (GR) soybean changed the herbicide use patterns for over a decade (from 2000 to 2010) from PRE followed by POST herbicide application to primarily POST, mostly based on glyphosate (Duke, 2015; Givens et al., 2009; Powles, 2008). However, overreliance on glyphosate resulted in weed species shifts and evolution to GR weeds (Culpepper, 2006; Johnson et al., 2009; Owen, 2008; Webster and Nichols, 2012). Currently, there are six cases of GR weeds in Nebraska (Heap, 2017), and new cases are expected to appear shortly. Therefore, there is an urgent need for reducing glyphosate dependence in soybean. In soybean weed management, a strategy might be to include herbicide programs with effective PRE- and POST-applied herbicide mixtures of different site(s) of action (SOA) (Norsworthy et al., 2012).

Crop Management

Core Ideas

- Herbicide premixes provided good (>90%) broadleaf and grass weed control in Nebraska.
- Preemergence-applied herbicide premixes with different sites of action will help manage resistance weeds.
- Preemergence-applied herbicides should be a foundation for weed management in soybean.

Maxwel C. Oliveira, Jon E. Scott, and Stevan Z. Knezevic, Dep. of Agronomy and Horticulture, Univ. of Nebraska-Lincoln, Concord, NE 68728; Dave Feist, Asset Manager, ADAMA, Fort Collins, CO 80526; Steve Eskelsen, Innovation Leader, ADAMA, Richland, WA 99352. *Corresponding author (sknezevic2@unl.edu).

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Abbreviations: ALS, acetolactate synthase; DAPOST, days after postemergence treatment; DAPRE, days after preemergence treatment; GR, glyphosate-resistant; POST, postemergence treatment; PPO, protoporphyrinogen oxidase; PRE, preemergence treatment; PSII, Photosystem II; SOA, site(s) of action.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.304	foot, ft	meter, m
2.54	inch	centimeter, cm (10^{-2} m)
1.609	mile, mi	kilometer, km (10^{-3} m)
0.405	acre	hectare, ha
67.19	60-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha
9.35	gallon per acre, gal/acre	liter per hectare, L/ha
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
6.90	pound per square inch, lb/sq inch	kilopascal, kPa
5/9 (°F – 32)	Fahrenheit, °F	Celsius, °C

Preemergence-applied herbicide can protect crop yield loss in the early season when weeds are the most competitive (Butts et al., 2017; Tursun et al., 2016). In addition, there are well-documented benefits of utilizing premixes of PRE- and POST-applied herbicide mixtures, especially in delaying herbicide resistance and providing season-long weed control (Aulakh and Jhala, 2015; Ganie et al., 2016; Johnson et al., 2012; Oliveira et al., 2017). Application of PRE herbicide was described as a foundation for kochia (*Kochia scoparia*) control (Kumar and Jha, 2015). Ellis and Griffin (2002) reported that when a PRE-applied herbicide was used, only a single POST glyphosate application was needed to control barnyardgrass (*Echinochloa crus-galli*), ivyleaf morningglory, prickly sida (*Sida spinosa*), hemp sesbania (*Sesbania herbacea*), and ragweed (*Ambrosia* spp.) in soybean.

The addition of effective herbicide SOA in PRE- and POST-applied programs could improve the effectiveness of weed control in soybean. Therefore, the main objective of this study was to evaluate the efficacy of several herbicides, and herbicides premixes applied PRE-only and POST-only for control of 11 troublesome weed species in eastern Nebraska.

Site Description

The experiments were conducted in 2014 and 2015 at the Haskell Agricultural Laboratory of the University of Nebraska-Lincoln in Concord, NE (42°23′1″ N, 96°59′18″ W). In 2014, at the research site, the soil type was loam with 2.7% organic matter and pH 7.6. In 2015, at different research site but the same location, the soil type was silty loam with 3.3% organic matter and pH 6.2. The GR soybean Mycogen 5N284R2 (2014) and GR soybean Pioneer 92Y70 (2015) were seeded at moderate plant populations of 149,000 (2014), and 180,000 (2015) seeds acre^{-1} in rows spaced 30 inches apart on 22 May 2014 and 9 June 2015. Fields were previously cropped with corn (*Zea mays*) and tilled prior planting. Monthly mean air temperature and rainfall data during the study period are provided (Table 1).

Table 1. Mean monthly air temperature and rainfall from May through October in 2014 and 2015, Concord, NE.

	Air temperature			Rainfall		
Month†	2014	2015	20-year avg.	2014	2015	20-year avg.
		°F			inches	
May	59	58	60	3.4	2.7	3.9
June	74	69	69	20.7	4.9	4.7
July	70	73	74	4.4	5.4	2.6
Aug.	71	70	71	5.9	3.3	3.1
Sept.	62	67	63	2.8	8.0	2.1
Oct.	52	53	50	1.1	0.7	2.0

† Weather data were obtained from the High Plains Regional Climate Center (http://www.hprcc.unl.edu).

Experimental Procedures

The experimental unit was a plot of 6.7-ft width by a 40-ft length with 11 weed species seeded perpendicular to soybean rows. Seven broadleaf and four grass weed species were seeded with push planters 30 inches apart 5 days before planting GR soybeans. The non-GR weed species included: ivyleaf morningglory, kochia, common lambsquarters, velvetleaf (*Abutilon theophrasti*), Venice mallow (*Hibiscus trionum*), common waterhemp, redroot pigweed, yellow foxtail (*Setaria pumila*), green foxtail (*Setaria viridis*), barnyardgrass, and fall panicum (*Panicum dichotomiflorum*) (Azlin Seed Service, Leland, MS). Uniform patch of endemic populations of suspected acetolactate synthase (ALS)–resistant common waterhemp and velvetleaf were also allowed to grow and were evaluated in each experimental unit.

The experiment was set up as a randomized complete block design with three replicates and 14 herbicide treatments (nine PRE-only and five POST-only) (Table 2). A nontreated control was included for comparison. The application of PRE herbicides was on 23 May 2014 and on 10 June 2015. The POST herbicides were applied when weeds were 3 to 4 inches tall. Herbicide treatments were applied with a CO_2–pressurized backpack sprayer equipped with four nozzles, spaced 20 inches apart. The backpack sprayer was calibrated to deliver

Table 2. Herbicide common names, site of action group, application timing, rates, and adjuvant of the herbicide treatments utilized in field experiments in 2014 and 2015, Concord, NE.

Herbicide treatment†	SOA group‡	Timing§	Rate	Adjuvant¶
			lb a.i. acre^{-1}	
metolachlor + imazethapyr	15+2	PRE	1.31	–
metolachlor	15	PRE	1.25	–
imazethapyr	2	PRE	0.06	–
fomesafen	14	PRE	0.24	–
fomesafen + imazethapyr	14+2	PRE	0.31	–
flumioxazin + imazethapyr	14+2	PRE	0.15	–
flumioxazin	14	PRE	0.06	–
flumioxazin + metribuzin	14+5	PRE	0.35	–
metribuzin	5	PRE	0.25	–
metolachlor + imazethapyr	15+5	POST	1.31	NIS 0.25% v/v
metolachlor	15	POST	1.25	NIS 0.25% v/v
imazethapyr	2	POST	0.06	NIS 0.25% v/v
fomesafen	14	POST	0.24	NIS 0.25% v/v
fomesafen + imazethapyr	14+2	POST	0.31	NIS 0.25% v/v

† Herbicide premixes, +.

‡ SOA, herbicide site of action group according to Weed Science Society of America.

§ PRE, preemergence; POST, postemergence.

¶ NIS, nonionic surfactant (Induce, Helena Chemical Co., Collierville, TN) was added to each postemergence treatment.

15 gal acre^{-1} aqueous solution through the Turbo TeeJet 11002 (PRE) and 110015 (POST) flat sprayer nozzles (Spraying Systems Co., Wheaton, IL) at 20 lb sq. inch^{-1} (PRE) and 36 lb sq. inch^{-1} (POST) at a speed of 2.7 mi h^{-1}.

Weed control was visually evaluated using a scale of 0 to 100% control (where 0 = no injury and 100 = plant death). Control ratings were based on symptoms such as chlorosis, necrosis, and stunting of plants compared with nontreated plants. Weed control was assessed at 40 and 60 days after preemergence treatment (DAPRE), and 10 and 30 days after postemergence treatment (DAPOST). Soybeans were harvested from the two middle rows of each experimental unit on 15 Oct. 2015, with yield reported at 13% moisture. Soybean yield data from 2014 were not collected; therefore, only 2015 soybean yield is presented in this study.

Data Analysis

The ANOVA was performed using PROC GLIMMIX in the SAS statistical software (SAS Institute, 2016); year and treatments (weed control and yield) were considered fixed and block as random effects. The Shapiro–Wilk test was done to test normality with PROC GLM in the SAS. In addition, in the SAS, the homogeneity of residual variance was tested with PROC UNIVARIATE. Control and soybean yields (bu acre^{-1}) were analyzed with β and normal distribution, respectively, to meet assumptions of the variance analysis. Weed control was compared at 40 DAPRE to 10 DAPOST (the same rating day), and 60 DAPRE to 30 DAPOST (the same rating day). If ANOVA indicated treatment effects, the means were separated at $P \leq 0.05$ with Fisher's protected LSD test.

The treatment $\times$ year interaction was not significant for the experiment; therefore, data were combined across the two years of experiments.

Broadleaf Weed Control

In general, PRE-applied herbicides controlled broadleaf weeds better than POST-applied herbicides (Table 3). Most of the PRE-applied herbicides controlled broadleaf weeds ≥85% (Table 3). For example, greatest control was observed with metolachlor + imazethapyr, fomesafen + imazethapyr, flumioxazin + imazethapyr, and flumioxazin + metribuzin, which provided ≥90% broadleaf weed control at 40 and 60 DAPRE. Metribuzin and flumioxazin applied PRE also controlled broadleaf weeds ≥89% except for ivyleaf morningglory (Table 3). Jones and Griffin (2008) have also documented less control of morningglory with PRE-applied metribuzin and flumioxazin. Furthermore, fomesafen and imazethapyr controlled broadleaf weeds ≥85% except for common waterhemp with imazethapyr 40 DAPRE. Fomesafen applied PRE resulted in variable control (31–79%) of ivyleaf morningglory and velvetleaf (Table 3).

Results showed the effective broad-spectrum weed control when premixes from Group 2 (ALS-inhibitors), Group 5 (Photosystem II [PSII]-inhibitors), Group 14 (protoporphyrinogen oxidase [PPO]-inhibitors), and Group 15 (long-chain fatty acid-inhibitors) herbicides. Similarly, others reported that PRE application of PPO herbicides tank-mixed with ALS-inhibiting herbicides provided an effective control of broadleaf species (Belfry et al., 2015; Walsh et al., 2015); including kochia, Russian thistle (*Salsola tragus*), field bindweed (*Convolvulus arvensis*), velvetleaf, common lambsquarters, and yellow sweetclover (*Melilotus officinalis*) in Nebraska (Knezevic et al., 2009). Hausman et al. (2013) also reported that PRE-applied metribuzin and flumioxazin alone provided 92% waterhemp control at 60 DAPRE in soybean.

The POST-applied treatments with the greatest control of broadleaf weeds were fomesafen and fomesafen + imazethapyr (Table 3). These herbicides controlled ivyleaf morningglory, common lambsquarters, common waterhemp, and redroot pigweed ≥85% (Table 3). Moreover, metolachlor + imazethapyr provided ≥90% control of ivyleaf morningglory and redroot pigweed 30 DAPOST. Similarly, Cantwell et al. (1989) reported imazethapyr alone or in mixtures with PSII- and PPO-inhibitors as an effective herbicide to control pigweeds, common lambsquarters, and velvetleaf in soybeans. Imazethapyr alone provided ≥94% common lambsquarters and redroot pigweed control at 30 DAPOST, as well as 50 to

Table 3. Efficacy of preemergence- and postemergence-applied herbicide treatments for broadleaf weeds control in 2014 and 2015, Concord, NE.

Herbicide treatment†		Broadleaf weed species‡													
		ivyleaf morningglory		kochia		common lambsquarters		velvetleaf		Venice mallow		common waterhemp		redroot pigweed	
	DAPRE§	40	60	40	60	40	60	40	60	40	60	40	60	40	60
	DAPOST§	10	30	10	30	10	30	10	30	10	30	10	30	10	30
	Timing¶														
		%													
metolachlor + imazethapyr	PRE	94 ab	92 ab	97 a	97 a	96 a	96 a	98 a	95 ab	98 a	97 a	91 b	90 c	98 a	97 a
metolachlor	PRE	40 f	29 e	28 d	46 e	87 abc	31 b	50 d	32 e	67 c	28 c	91 b	92 abc	65 d	55 b
imazethapyr	PRE	96 a	87 bc	85 b	97 a	95 a	94 a	98 a	96 a	98 a	97 a	79 c	91 bc	98 a	97 a
fomesafen	PRE	78 cd	31 e	97 a	97 a	89 abc	87 a	68 c	40 e	92 b	89 a	96 ab	96 ab	96 ab	97 a
fomesafen + imazethapyr	PRE	96 a	94 a	97 a	97 a	96 a	94 a	98 a	96 a	98 a	91 a	97 a	97 a	98 a	97 a
flumioxazin + imazethapyr	PRE	96 a	95 a	97 a	97 a	96 a	96 a	98 a	97 a	98 a	95 a	97 a	96 ab	98 a	97 a
flumioxazin	PRE	87 bc	79 cd	95 ab	97 a	96 a	96 a	97 a	94 ab	98 a	97 a	96 ab	93 abc	97 ab	96 a
flumioxazin + metribuzin	PRE	92 ab	92 ab	97 a	97 a	96 a	96 a	98 a	96 a	98 a	97 a	97 a	96 ab	98 a	97 a
metribuzin	PRE	53 e	70 d	97 a	97 a	93 ab	93 a	97 a	96 a	98 a	97 a	95 ab	89 c	92 c	97 a
metolachlor + imazethapyr	POST	48 ef	91 ab	66 c	89 ab	81 bc	89 a	77 b	86 cd	10 d	17 c	17 d	55 d	91 c	96 a
metolachlor	POST	47 ef	34 e	13 d	13 f	16 d	31 b	19 e	15 f	14 d	12 c	26 d	32 e	30 e	22 c
imazethapyr	POST	75 d	69 d	50 c	61 de	77 c	94 a	66 c	89 bc	10 d	25 c	26 d	34 e	95 abc	97 a
fomesafen	POST	93 ab	90 ab	50 c	69 cd	86 abc	93 a	63 c	77 d	92 b	94 a	94 ab	94 abc	93 bc	96 a
fomesafen + imazethapyr	POST	95 a	90 ab	67 c	86 bc	86 abc	88 a	78 b	83 cd	60 c	66 b	96 ab	95 abc	94 bc	96 a

† Herbicide premixes, +.

‡ Means presented within each column with no common letter(s) are significantly different according to Fisher's Protected LSD test where $P \leq 0.05$.

§ DAPRE, days after preemergence herbicide application; DAPOST, days after postemergence herbicide application.

¶ PRE, preemergence; POST, postemergence.

80% of ivyleaf morningglory, kochia, and velvetleaf. These results are in agreement with research that demonstrated incomplete control (≤66%) of ivyleaf morningglory and velvetleaf with imazethapyr, which was due to differential herbicide translocation (Hoss et al., 2003).

The relative low control (≤35%) of common waterhemp by POST application of imazethapyr was likely due to the presence of ALS-resistance in local waterhemp population. The occurrence of resistant weeds will require herbicide programs with multiple effective SOA. For example, a better strategy for ALS- and glyphosate-resistant waterhemp biotype control in glufosinate-tolerant soybeans would be a combination of PRE- followed by POST-applied herbicides rather than either one- or two-pass POST-applied herbicide programs alone (Jhala et al., 2017).

Grass Weed Control

In general, PRE-applied herbicides controlled grassy weeds better compared with POST-applied herbicides (Table 4). Metolachlor + imazethapyr, fomesafen + imazethapyr, flumioxazin + imazethapyr, flumioxazin + metribuzin, metolachlor, and flumioxazin applied PRE provided ≥80% control of yellow foxtail, green foxtail, barnyardgrass, and fall panicum 40 and 60 DAPRE (Table 4). Imazethapyr applied PRE controlled grasses ≥80% 60 DAPRE. Also, fomesafen provided ≥86% control of yellow foxtail, green foxtail, and barnyardgrass 40 DAPRE (Table 4). Walsh et al. (2015) also reported acceptable grass control (≥75%) and improved soybean yields with PRE application of PPO herbicides in a tank mix with imazethapyr. Moreover, imazethapyr in mixtures with PPO herbicides and metribuzin provided complete control of green foxtail at two weeks after soybean emergence (Belfry et al., 2016).

Most POST-applied herbicide treatments did not provide acceptable grass control (≥75%), except imazethapyr, fomesafen + imazethapyr, and metolachlor + imazethapyr, which provided 85 to 91% green foxtail control (Table 4). Therefore, effective graminicide herbicides should be added to the tank to enhance grass control. Several studies also recommended tank-mixing glyphosate with other SOA in POST applications to improve broad-spectrum weed control (Chahal et al., 2014; Jhala et al., 2014; Knezevic et al., 2009; Riley and Bradley, 2014; Shaw and Arnold, 2002).

Table 4. Efficacy of preemergence- and postemergence-applied herbicide programs on grass weed control in 2014 and 2015, Concord, NE.

		Grass weed species‡							
		yellow foxtail		green foxtail		barnyardgrass		fall panicum	
	DAPRE§	40	60	40	60	40	60	40	60
	DAPOST§	10	30	10	30	10	30	10	30
Herbicide treatment†	Timing¶								
		%							
metolachlor + imazethapyr	PRE	95 a	97 a	96 a	97 a	95 a	96 a	95 a	95 a
metolachlor	PRE	95 a	95 ab	93 ab	92 cde	95 a	92 abc	92 ab	92 ab
imazethapyr	PRE	75 bc	90 b	93 ab	90 de	77 b	84 bcd	83 abc	83 abc
fomesafen	PRE	88 ab	76 c	95 ab	92 b–e	86 ab	76 cd	74 cde	73 cde
fomesafen + imazethapyr	PRE	91 a	96 ab	94 ab	96 abc	85 ab	94 ab	89 abc	89 abc
flumioxazin + imazethapyr	PRE	94 a	96 ab	96 a	97 ab	91 ab	94 ab	89 abc	89 abc
flumioxazin	PRE	90 ab	96 ab	94 ab	94 a–d	80 ab	82 bcd	89 abc	89 abc
flumioxazin + metribuzin	PRE	97 a	96 ab	97 a	97 ab	95 a	94 ab	89 abc	89 abc
metribuzin	PRE	66 c	56 d	84 c	68 g	73 b	72 d	76 bcd	76 bcd
metolachlor + imazethapyr	POST	34 d	73 c	89 bc	86 ef	37 c	37 ef	46 ef	46 ef
metolachlor	POST	23 d	23 e	85 d	56 gh	21 c	19 f	27 f	27 f
imazethapyr	POST	34 d	47 d	91 c	87 ef	35 c	40 ef	44 f	44 f
fomesafen	POST	34 d	47 d	57 d	56 h	32 c	40 ef	35 f	35 f
fomesafen + imazethapyr	POST	37 d	53 d	85 c	79 f	36 c	63 de	50 def	50 def

† Herbicide premixes, +.

‡ Means presented within each column with no common letter(s) are significantly different according to Fisher's Protected LSD test where $P \leq 0.05$.

§ DAPRE, days after preemergence herbicide application; DAPOST, days after postemergence herbicide application.

¶ PRE, preemergence; POST, postemergence.

Soybean Yields

Greater soybean yields were achieved in plots with PRE-applied herbicides (Table 5). Soybean yields were highest ($\geq$57.2 bu acre^{-1}) when metolachlor + imazethapyr, fomesafen + imazethapyr, flumioxazin + imazethapyr, flumioxazin + metribuzin, and metribuzin alone were applied PRE and fomesafen + imazethapyr applied POST (Table 5). Lowest soybean yields were in the plots with POST-applied treatments. Lower soybean yields were likely due to competition from grassy weed species, which were not well controlled by the POST-applied-only treatments (Table 5). Several studies have demonstrated the competitive potential of grasses to reduce soybean yields (Alms et al., 2016; Guglielmini et al., 2016; Hock et al., 2006; Vail and Oliver, 1993).

Metolachlor + imazethapyr, metolachlor, and fomesafen applied PRE provided significantly greater soybean yields compared with POST timing (Table 5). There was no difference detected between imazethapyr or fomesafen + imazethapyr applied PRE vs. POST. Though fomesafen + imazethapyr applied POST did not provide complete control of certain weeds (e.g., Venice mallow and velvetleaf), this premix reduced growth and competitive ability of other weeds, which has also been previously documented (Holloway and Shaw, 1995). The enhanced weed control was the major contribution for greater soybean yields in PRE-applied treatments compared with POST-applied.

Table 5. Soybean yields after application of preemergence- and postemergence-applied herbicide treatments in 2015, Concord, NE.

Herbicide treatment†	Timing‡	Yield§
		bu acre^{-1}
nontreated control	–	30.0 f
metolachlor + imazethapyr	PRE	59.4 ab
metolachlor	PRE	49.8 cd
imazethapyr	PRE	50.1 cd
fomesafen	PRE	49.0 d
fomesafen + imazethapyr	PRE	61.4 a
flumioxazin + imazethapyr	PRE	61.7 a
flumioxazin	PRE	57.2 abc
flumioxazin + metribuzin	PRE	59.1 ab
metribuzin	PRE	57.8 ab
metolachlor + imazethapyr	POST	35.9 ef
metolachlor	POST	32.1 f
imazethapyr	POST	52.2 bcd
fomesafen	POST	40.4 e
fomesafen + imazethapyr	POST	57.3 abc
standard error		3.7

† Herbicide premixes, +.

‡ PRE, preemergence; POST, postemergence.

§ Means presented within each column with no common letter(s) are significantly different according to Fisher's Protected LSD test where $P \leq 0.05$.

There was no soybean injury in plots with PRE-applied herbicide. In contrast, few POST-applied herbicides (metolachlor + imazethapyr, metolachlor, and imazethapyr) caused 10 to 15% crop injury, while fomesafen and fomesafen + imazethapyr caused 15 to 25% crop injury at 10 DAPOST (data not shown). Other studies also reported 10 to 25% injury due to POST application of PPO-inhibitor herbicides (Aulakh et al., 2016; Sarangi et al., 2017).

The herbicide premixes tested in this study can provide alternative control options for ivyleaf morningglory, kochia, common lambsquarters, velvetleaf, Venice mallow, common waterhemp, redroot pigweed, yellow foxtail, green foxtail, barnyardgrass, and fall panicum in Nebraska. Growers need to know the spectrum of weed species on their farm, the level of weed infestation, herbicide efficacy, and environmental conditions when designing the proper herbicide program. Other factors, such as rainfall pattern and soil moisture, can also influence herbicide efficacy (Stewart et al., 2010, 2012).

The application of PRE herbicide protected soybean yields by controlling early-germinating weeds (first 3–4 weeks) (Oliveira et al., 2016), which also provides the flexibility for a more timely POST application. Most importantly, PRE-applied herbicides would also provide additional SOA and alternative options for controlling GR weeds in Nebraska and elsewhere.

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