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Comparison of a diflufenican-containing premixture to current commercial standards for residual Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus*) control

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Abstract

With Palmer amaranth and waterhemp evolving resistance to nine and six different sites of action (SOAs) globally, soybean producers continue to search for new options to control these problematic weeds. Bayer CropScience has announced its intentions to launch a Convintro™ brand of herbicides, one being a three-way premixture for preemergence use in soybean. The premixture will contain diflufenican (WSSA Group 12), metribuzin (WSSA Group 5), and flufenacet (WSSA Group 15), adding a new SOA for soybean producers throughout the United States. With the anticipated launch of the premixture, research is needed to evaluate the length of residual control provided by the new herbicide. Research trials were conducted in Fayetteville and Keiser, AR, and Morrice, MI, in 2022 and 2023. A 0.17:0.35:0.48 ratio of a diflufenican:metribuzin:flufenacet (DFF)-containing premixture was applied alone and in combination with additional metribuzin and dicamba. Also, metribuzin, acetochlor, a *S*-metolachlor:metribuzin premixture, and a flumioxazin:pyroxasulfone:metribuzin premixture were applied preemergence. The DFF-containing premixture was more effective in reducing Palmer amaranth/waterhemp emergence than acetochlor in four of six trials at 28 d after treatment (DAT). Palmer amaranth and waterhemp densities in plots treated with the DFF-containing premixture exhibited similar results to plots treated with the *S*-metolachlor:metribuzin premixture and the flumioxazin:pyroxasulfone:metribuzin premixture at 28 DAT. By 56 DAT, Palmer amaranth and waterhemp densities were comparable or superior in plots with the DFF-containing premixture than in those treated with acetochlor and metribuzin, and the *S*-metolachlor:metribuzin premixture at five of six sites. The addition of dicamba or metribuzin to the DFF-containing premixture did not reduce Palmer amaranth or waterhemp density compared to the DFF-containing premixture at 28 or 56 DAT. Overall, the DFF-containing premixture generally provided greater or comparable control over several standard herbicides, providing growers a new product for preemergence control of *Amaranthus* species in soybean fields.

Introduction

Palmer amaranth and waterhemp are the two most problematic weeds in soybean production in the United States (Van Wychen 2022). Characteristics of *Amaranthus* species that make them problematic include high seed production, rapid growth, extended germination periods, and drought tolerance (Horak and Loughin 2000; Jha et al. 2009; Keeley et al. 1987; Sellers et al. 2003), resulting in a high degree of interference with a wide array of crops (Monks and Oliver 1988). Yield reductions of up to 60% have been reported in cotton (MacRae et al. 2013), 91% in corn (Massinga et al. 2001), and 78% in soybean (Bensch et al. 2003) from Palmer amaranth interference.

With the introduction of the glyphosate-resistant soybean, producers across the United States began to adopt the technology, quickly shifting management strategies and relying upon sequential postemergence applications of glyphosate to control weeds such as Palmer amaranth and waterhemp (Duke 2014; Powles 2008). With the heavy reliance on glyphosate to control weeds, herbicide diversity decreased, leading to the evolution of glyphosate resistance in weeds

Table 1. Soil description, planting date, application date, emergence date, and total rainfall for the three experimental locations in 2022 and 2023.[a]

	Location					
	Fayetteville, AR		Morrice, MI		Keiser, AR	
	2022	2023	2022	2023	2022	2023
Soil series[b]	Leaf		Macomb		Sharkey	
Soil texture	Silt loam		Sandy clay loam		Clay	
Sand (%)	18	–[c]	49	36	17	–[c]
Silt (%)	69	–	26	37	34	–
Clay (%)	13	–	25	27	49	–
OM (%)	1.6	–	2.6	1.3	2.3	–
pH	6.6	–	6.1	6.1	6.9	–
Planting date	May 19	May 9	May 24	May 23	May 4	May 17
Application date	May 19	May 10	May 24	May 23	May 4	May 18
Emergence date	May 25	May 18	May 29	May 30	May 9	May 22
Total rainfall 28 DAT (cm)	11.4	10.8	3.70	0.50	10.4	5.2

[a]Abbreviations: DAT, days after treatment; OM, organic matter.
[b]For soil series and texture data see USDA-NRCS 2024.
[c]Trial was conducted in an adjacent location within the field in 2023.

such as Palmer amaranth and waterhemp (Powles 2008). Currently, these two weed species have evolved resistance to glyphosate in 26 and 18 states, respectively (Heap 2024), causing producers to alter their weed management strategies.

With glyphosate-resistant Palmer amaranth and waterhemp spreading across the United States, producers began to focus on controlling the most troublesome weeds in their fields. Current recommendations to control herbicide-resistant *Amaranthus* species include applying a preemergence herbicide followed by sequential postemergence applications in combination with soil residual herbicides (Kohrt and Sprague 2017). Additionally, to slow the evolution of resistance, recommendations include using herbicides in combination that contain multiple sites of action (SOAs) that are effective against the most troublesome weeds (Norsworthy et al. 2012). Overall, a strong preemergence herbicide can protect crop yields by reducing early-season competition due to the delayed emergence of troublesome weed species (Tursun et al. 2016).

Currently, herbicides belonging to Groups 2, 3, 4, 5, 14, and 15 (as classified by the Weed Science Society of America [WSSA] and Herbicide Resistance Action Committee) are recommended for preemergence use in soybean (Barber et al. 2023). Pyroxasulfone (WSSA Group 15) and metribuzin (WSSA Group 5) controlled Palmer amaranth 88% and 78%, respectively, 28 days after treatment (DAT) (Houston et al. 2019). In addition, flumioxazin (WSSA Group 14) + pyroxasulfone provided >95% control of Palmer amaranth 3 to 4 wk after application (Meyer et al. 2015). Although these herbicides can still offer high levels of control against problematic weeds, Palmer amaranth and waterhemp have evolved resistance to nine and six different SOAs, respectively (Heap 2024). Therefore, herbicide manufacturers continue to search for new SOAs for producers to integrate into their weed management programs.

In 2021, Bayer CropScience announced its intentions to launch a Convintro™ brand of herbicides, one being a premixture that will be labeled for preemergence use in soybean (Anonymous 2021). The premixture will consist of diflufenican (WSSA Group 12), metribuzin (WSSA Group 5), and flufenacet (WSSA Group 15) and will be targeted at control of *Amaranthus* species. Currently, norflurazon, another WSSA Group 12 herbicide, is labeled for use in soybean production, but is restricted to use in the mid-southern United States (Anonymous 2015). Therefore, if labeled, diflufenican will be the first Group 12 herbicide labeled for use in soybean throughout the United States that will allow producers to incorporate multiple SOAs to slow the evolution of herbicide resistance (Norsworthy et al. 2012).

Diflufenican is a phytoene desaturase inhibitor, with the typical plant symptomology being bleaching of leaf tissue due to the accumulation of phytoene in place of carotenoid formation (Bartels and Watson 1978). Diflufenican was originally discovered in the 1980s and registered for preemergence and early postemergence use in European cereal production (Cramp et al. 1987). When used preemergence on wheat (*Triticum aestivum* L.), diflufenican effectively controlled broadleaf weed species, but the overall spectrum of the herbicide appears to be limited (Haynes and Kirkwood 1992). Because control is limited to broadleaf weeds, the herbicide is typically paired with additional herbicides to achieve broad-spectrum weed control. For instance, diflufenican + flufenacet, a premixture registered for use in European cereal production, reduced the growth of blackgrass (*Alopecurus myosuroides* Huds.), a problematic weed in wheat fields, by 90% (Ducker et al. 2019).

This research aims to understand the length of residual control provided by the diflufenican:metribuzin:flufenacet premixture (hereafter referred to as DFF-containing premixture) relative to other herbicides commonly used in soybean. The need for dicamba or additional metribuzin for the DFF-containing premixture is also examined.

Materials and Methods

Field experiments were conducted at the Milo J. Shult Agriculture Research and Extension Center in Fayetteville, AR (36.09326°N, 94.17380°W), near Morrice, MI (42.838435°N, 84.149501°W), and the Northeast Arkansas Research and Extension Center in Keiser, AR (35.67491°N, 90.08076°W), in 2022 and 2023 (Table 1). The seedbed was prepared using conventional tillage, including chisel in Michigan disk, and cultivation at all locations, and bedding at the Arkansas locations. Following ground preparation, soybean variety AG45XF0 (Bayer CropScience, St. Louis, MO) was planted at 346,000 seeds ha^{-1} in Fayetteville and Keiser, and AG26XF3 (Bayer CropScience) in Morrice, 370,000 seeds ha^{-1} using a four-row vacuum planter. Plots measured 7.6 m in length at all locations, and 3.7 m in width (91-cm spacing) at the Fayetteville location, 3.9 m in width (97-cm spacing) at Keiser, and 3.0 m in width (76-cm spacing) at Morrice. Preplant fertilizer was

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Table 2. Herbicide information for all products used in the experiments.

Herbicide	Trade name	Manufacturer
Metribuzin	Tricor® 4L[a]	UPL, King of Prussia, PA
Metribuzin	Mauler[b]	Valent USA, San Ramon, CA
Acetochlor	Warrant®	Bayer CropScience, St. Louis, MO
S-metolachlor, metribuzin	Boundary® 6.5 EC	Syngenta USA, Greensboro, NC
Diflufenican, metribuzin, flufenacet	Convintro™	Bayer CropScience
Dicamba	Temima® with VaporGrip® Technology	Bayer CropScience
Flumioxazin, pyroxasulfone, metribuzin	Fierce® MTZ	Valent USA

[a]Used in Arkansas.
[b]Used in Michigan.

Table 3. Herbicide treatments evaluated at three locations in Arkansas and Michigan.

Trade name	Herbicide	Fayetteville, AR[a]	Morrice, MI[b]	Keiser, AR[c]
		Rate		
		———g ai/ae ha^{-1}———		
Nontreated	n/a	n/a	n/a	n/a
Warrant	Acetochlor	1,260	1,260	1,260
Tricor/Mauler	Metribuzin	560	560	1,120
Boundary	*S*-metolachlor	1,100	1,100	1,840
	Metribuzin	260	260	440
Convintro	Diflufenican	120	150	180
	Metribuzin	240	300	360
	Flufenacet	330	410	490
Convintro + Tricor/ Mauler	Diflufenican	120	150	180
	Metribuzin	240	300	360
	Flufenacet	330	410	490
	Metribuzin	320	320	760
Fierce MTZ	Flumioxazin	70	70	105
	Pyroxasulfone	90	90	135
	Metribuzin	210	210	315
Convintro + Xtendimax	Diflufenican	120	150	180
	Metribuzin	240	300	360
	Flufenacet	330	410	490
	Dicamba	560	560	560

[a]Herbicide rates used at the Fayetteville, AR, location are based on a silt loam soil.
[b]Herbicide rates used at the Morrice, MI, location are based on a sandy clay loam soil.
[c]Herbicide rates used at the Keiser, AR, location are based on a silty clay soil.

applied when needed based on soil test results and fertilizer recommendations from the University of Arkansas and Michigan State University for soybean (Ross et al. 2022; Warncke et al. 2009). Furrow or overhead irrigation occurred if 2.5 cm of rainfall did not occur within a 7-d period for trials conducted in Arkansas, whereas trials in Michigan were conducted under nonirrigated conditions.

The experiment was designed as a randomized complete block with four replications and one factor (herbicide treatment). Seven different preemergence herbicides or herbicide combinations were evaluated in this study (Table 2). Due to the differences in soil texture across the three different locations, herbicide rates were adjusted for each soil type (Table 3). Herbicides were applied using a CO_2-pressurized backpack sprayer and a four-nozzle boom, using TeeJet AIXR 110015 nozzles (Spraying Systems, Inc., Glendale Heights, IL) calibrated to deliver 140 L ha^{-1} at 4.8 km h^{-1} at the Fayetteville and Keiser locations. At the Michigan location herbicides were applied using a tractor-mounted sprayer using TeeJet AIXR 11003 nozzles calibrated to deliver 178 L ha^{-1} at 6.1 km h^{-1}. Visible injury ratings were collected on a scale of 0% to 100%, with 0% being no crop injury and 100% being complete crop death 14, 28, and 42 DAT in 2022 and 2023 at the Fayetteville and Keiser sites, and 28, 35, and 42 DAT in 2023 at the Morrice site (Frans and Talbert 1977). Palmer amaranth (in Arkansas) and waterhemp (in Michigan) counts in two 0.5-m^{-2} quadrats per plot were collected 14, 28, 42, and 56 DAT at all locations. Following counts, the entire trial was oversprayed with glufosinate at 656 g ai ha^{-1} at each evaluation. Grain yield was not collected because applications of glufosinate occurred after the R1 growth stage.

Data Analysis

Statistical analysis was performed using R Studio software (v. 4.3.2; R Core Team 2022), and JMP Pro software v. 17.2; SAS Institute, Cary, NC). Cumulative Palmer amaranth plus waterhemp counts were fitted to a generalized linear mixed model using a Poisson distribution (Gbur et al. 2012) with herbicide and site-year as fixed effects and replication as a random effect. At each evaluation time, the interaction of herbicide and site-year was significant, which is partially attributed to the drastic differences in Palmer amaranth density between years and differences in rainfall. Therefore, locations and site-years were analyzed separately to understand the consistency of each herbicide within the environments and years across different *Amaranthus* species. Means were separated using Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$) to reduce any type I error. Percent reduction in Palmer amaranth and waterhemp density was calculated relative to the nontreated check using the formula below:

$$\left(1 - \left[\frac{Average\ density\ of\ treated\ plot}{Average\ density\ of\ nontreated\ plot}\right]\right)*100 \qquad \text{Eq.1}$$

Injury data were bound between 0 and 1 and fit to a generalized linear mixed-effect model (Stroup 2015) using the *glmmTMB* function (GLMMTMB package in R; Brooks et al. 2017) with a beta distribution (Gbur et al. 2012). Herbicide was considered a fixed effect, and replication was considered a random effect. Data were analyzed by location and year due to the differences in injury observed between years at the various research sites. An analysis of variance (CAR package) was performed on the fitted model (Fox and Weisberg 2019) with the Type III Wald χ-square test. Estimated marginal means (using the EMMMEANS package in R; Searle et al. 1980) were obtained and separated using Tukey's HSD test ($\alpha = 0.05$). A compact letter display (using the MULTCOMP package in R; Hothorn et al. 2008) was generated to visually represent groups that were significantly different.

Results and Discussion

The DFF-containing premixture was evaluated against a range of herbicides with one, two, three, or four SOAs for effectiveness on Palmer amaranth and waterhemp. In all site-years, Palmer amaranth density was reduced by 94% or more by the DFF-containing premixture at 14 DAT relative to the nontreated plants. The DFF-containing premixture was more effective at reducing Palmer amaranth density than acetochlor in both years at Keiser by 14 DAT, but it was not more effective than metribuzin (Table 4).

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Table 4. Influence of herbicide treatment on cumulative Palmer amaranth density 14 DAT at two locations in Arkansas, and waterhemp density at the Michigan location in 2022 and 2023.[a–d]

		Cumulative Palmer amaranth density				Cumulative waterhemp density	
		Fayetteville, AR		Keiser, AR		Morrice, MI	
Treatment	SOA	2022	2023	2022	2023	2022	2023
		Plants m^{-2}					
Acetochlor	1	0.0 (100)	12.2 (82.7)	28.2 a (91.0)	11.7 a (77.6)	1.0 (99.7)	NA
Metribuzin	1	0.0 (100)	0.0 (100)	12.1 bc (96.1)	0.0 b (100)	0.0 (100)	NA
S-metol + Met	2	0.0 (100)	0.0 (100)	11.4 bc (96.4)	1.7 b (96.7)	0.0 (100)	NA
DFF premix	3	0.0 (100)	0.0 (100)	5.2 cd (98.3)	3.2 b (93.8)	0.3 (99.9)	NA
DFF premix + Met	3	0.0 (100)	0.0 (100)	13.4 b (95.7)	0.0 b (100)	0.0 (100)	NA
Flum + Pyro + Met	3	0.0 (100)	0.0 (100)	0.5 d (99.8)	2.2 b (93.8)	0.0 (100)	NA
DFF premix + Dic	4	0.0 (100)	0.0 (100)	6.9 bc (95.7)	0.5 b (99.0)	0.2 (100)	NA
P-value		1.000	0.0846	<0.0001	<0.0001	0.0541	NA

[a]Abbreviations: DAT, days after treatment; Dic, dicamba; DFF premix, diflufenican:metribuzin:flufenacet premixture; Flum, flumioxazin; Met, metribuzin; Pyro, pyroxasulfone; *S*-metol, *S*-metolachlor; SOA, site of action.
[b]Columns within year by location not containing the same letter are significantly different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using a generalized linear mixed model with JMP Pro software (v. 17.2) with a Poisson distribution.
[d]Numbers in parentheses represent percent reduction relative to the nontreated check.

Table 5. Influence of herbicide treatment on cumulative Palmer amaranth density 28 and waterhemp density in 2022 and 2023 at 28 d after treatment.[a–d]

		Cumulative Palmer amaranth density				Cumulative waterhemp density	
		Fayetteville, AR		Keiser, AR		Morrice, MI	
Treatment	SOA	2022	2023	2022	2023	2022	2023
		Plants m^{-2}					
Acetochlor	1	2.5 a (95.3)	13.2 a (81.4)	33.7 a (90.5)	17.1 a (89.2)	15.4 a (96.6)	1.2 ab (84.8)
Metribuzin	1	1.2 a (97.7)	0.1 b (99.9)	13.5 b (96.2)	1.5 b (98.4)	6.6 b (98.6)	1.3 ab (83.4)
S-metol. + Met	2	0.5 a (99.1)	0.1 b (99.8)	14.0 b (96.0)	4.5 b (97.2)	0.9 c (99.8)	3.3 a (55.8)
DFF premix	3	0.1 a (99.8)	0.2 b (99.7)	6.2 c (98.3)	5.7 b (96.4)	2.6 bc (99.9)	0.4 b (94.5)
DFF premix + Met	3	0.1 a (99.9)	0.0 b (100)	13.4 bc (96.3)	0.0 b (100)	1.3 c (99.7)	0.0 b (100)
Flum + Pyro + Met	3	0.4 a (99.2)	0.0 b (100)	0.7 d (99.8)	3.2 b (97.2)	0.0 c (100)	0.9 b (87.6)
DFF premix + Dic	4	0.2 a (99.8)	0.0 b (100)	7.4 bc (97.9)	2.5 b (98.0)	3.1 bc (99.3)	0.2 b (97.2)
P-value		0.0415	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Abbreviations: DAT, days after treatment; DFF premix, diflufenican:metribuzin:flufenacet premixture; Dic, dicamba; Flum, flumioxazin; Met, metribuzin; Pyro, pyroxasulfone; *S*-metol, *S*-metolachlor; SOA, site of action.
[b]Columns within year by location not containing the same letter are significantly different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using a generalized linear mixed model with JMP Pro software (v. 17.2) with a Poisson distribution.
[d]Numbers in parentheses represent percent reduction relative to the nontreated check.

By 28 DAT, acetochlor and metribuzin were less effective than the DFF-containing premixture at reducing the *Amaranthus* weed density in four site-years and one site-year, respectively (Table 5). The greater effectiveness of the DFF-containing premixture on Palmer amaranth and waterhemp compared to acetochlor and to a lesser extent metribuzin, generally continued through 42 and 56 DAT (Tables 6 and 7). Other researchers have found that acetochlor can provide >89% control of Palmer amaranth up to 14 DAT (Wiggins et al. 2016). However, residual Palmer amaranth control with acetochlor is short-lived, as less than 65% control was reported by 28 DAT. In other research, metribuzin at 420 g ai ha^{-1} averaged across three soil textures provided 68 to 71% Palmer amaranth control at 28 DAT in 2016 and 2017 (Houston et al. 2021). However, adding metribuzin to other commonly used preemergence herbicides, such as pyroxasulfone or flumioxazin, increased Palmer amaranth control (Houston et al. 2021). Since the DFF-containing premixture includes metribuzin in combination with two additional SOAs, the reduction in Palmer amaranth and waterhemp density compared to that of metribuzin is not surprising. Overall, the DFF-containing premixture appears to be more effective than acetochlor, and to a lesser extent metribuzin, both of which have single SOAs, providing longer residual control of Palmer amaranth and waterhemp.

The DFF-containing premixture was compared to a mixture of *S*-metolachlor plus metribuzin, a herbicide premixture widely used for Palmer amaranth control in soybean in the midsouthern United States (Schwartz-Lazaro et al. 2018). The *S*-metolachlor plus metribuzin premixture provides two SOAs with activity against Palmer amaranth and waterhemp. The effectiveness of DFF-containing premixture against Palmer amaranth was comparable to that of the *S*-metolachlor:metribuzin premixture at 14 DAT, but by 28 DAT, it was more effective at just one of four site-years (Table 5). Similarly, the DFF-containing premixture was more effective at controlling waterhemp than the *S*-metolachlor: metribuzin premixture at just one of two site-years. These trends held through 56 DAT. The DFF-containing premixture was less effective than the *S*-metolachlor:metribuzin premixture at just one site-year (Table 7). Except for the Keiser site in 2022, Palmer amaranth and waterhemp densities were reduced by more than 91% relative to the nontreated control by both the DFF-containing premixture and the *S*-metolachlor:metribuzin premixture. Similarly, other researchers found that the *S*-metolachlor:

Table 6. Influence of herbicide treatment on cumulative Palmer amaranth density and waterhemp density at 28 d after treatment in 2022 and 2023.[a–d]

		Cumulative Palmer amaranth density				Cumulative waterhemp density	
		Fayetteville, AR		Keiser, AR		Morrice, MI	
Treatment	SOA	2022	2023	2022	2023	2022	2023
		Plants m^{-2}					
Acetochlor	1	3.9 a (92.6)	18.7 a (74.6)	70.1 a (86.7)	19.4 a (90.2)	20.3 a (95.7)	3.6 bc (98.2)
Metribuzin	1	2.3 a (95.7)	2.3 b (96.8)	109.4 a (79.2)	2.7 cd (98.6)	14.5 ab (97.0)	5.8 a (97.2)
S-metol. + Met	2	1.1 a (97.8)	1.7 b (97.7)	71.5 b (86.4)	7.1 bc (96.4)	1.9 d (99.6)	9.4 a (94.7)
DFF premix	3	0.2 a (99.7)	1.6 b (97.8)	41.7 c (92.1)	10.1 b (94.9)	7.7 bc (98.4)	0.7 c (99.4)
DFF premix + Met	3	0.1 a (99.8)	1.5 b (97.9)	47.1 c (91.0)	0.7 d (99.6)	6.8 cd (98.6)	0.0 c (100)
Flum + Pyro + Met	3	0.4 a (99.2)	0.3 b (99.6)	5.3 d (98.9)	3.7 cd (98.6)	5.3 cd (98.9)	1.7 bc (98.6)
DFF premix + Dic	4	0.3 a (99.4)	1.2 b (98.4)	55.5 bc (89.4)	4.7 bcd (97.6)	7.7 bc (98.4)	0.4 c (99.7)
P-value		0.0065	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Abbreviations: DAT, days after treatment; Dic, dicamba; DFF premix, diflufenican:metribuzin:flufenacet premixture; Flum, flumioxazin; Met, metribuzin; Pyro, pyroxasulfone; *S*-metol, *S*-metolachlor; SOA, site of action.
[b]Columns within year by location not containing the same letter are significantly different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using a generalized linear mixed model using JMP Pro software (v. 17.2) with a Poisson distribution.
[d]Numbers in parentheses represent percent reduction relative to the nontreated check.

Table 7. Influence of herbicide treatment on cumulative Palmer amaranth density and waterhemp density at 56 d after treatment in 2022 and 2023.[a–d]

		Cumulative Palmer amaranth density					
		Fayetteville, AR		Keiser, AR		Morrice, MI	
Treatment	SOA	2022	2023	2022	2023	2022	2023
		Plants m^{-2}					
Acetochlor	1	7.6 a (87.0)	18.7 a (74.6)	122.9 bc (82.7)	33.1 a (84.1)	20.3 a (95.7)	6.4 bc (97.2)
Metribuzin	1	3.6 ab (93.9)	2.3 b (96.8)	198.1 a (72.1)	19.1 b (90.8)	14.5 ab (97.0)	11.6 ab (95.0)
S-metol. + Met	2	3.9 ab (93.3)	1.7 b (97.7)	191.0 a (73.1)	18.6 bc (91.1)	1.9 d (99.6)	15.9 a (93.1)
DFF premix	3	0.4 b (99.4)	1.6 b (97.8)	102.2 c (85.6)	15.2 bcd (92.7)	7.7 bc (98.4)	0.9 d (99.6)
DFF premix + Met	3	1.0 b (98.3)	1.5 b (97.9)	108.3 bc (84.7)	8.3 bc (96.0)	6.8 cd (98.6)	1.4 d (99.4)
Flum + Pyro + Met	3	1.1 b (98.2)	0.3 b (99.6)	34.3 cd (95.2)	13.8 bcd (93.4)	5.3 cd (98.9)	2.0 cd (99.1)
DFF premix + Dic	4	0.6 b (98.9)	1.2 b (98.4)	131.6 b (81.4)	10.0 cd (95.2)	8.2 bc (98.3)	0.5 d (99.8)
P-value		0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]Abbreviations: DAT, days after treatment; Dic, dicamba; Met, metribuzin; DFF premix, diflufenican:metribuzin:flufenacet premixture; Flum, flumioxazin; Pyro, pyroxasulfone; *S*-metol, *S*-metolachlor.
[b]Columns within year by location not containing the same letter are significantly different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using a generalized linear mixed model using JMP Pro software (v. 17.2) with a Poisson distribution.
[d]Numbers in parentheses represent percent reduction relative to the nontreated check.

metribuzin premixture controlled common waterhemp (*A. rudis* Sauer) by 94% or more through 35 DAT (Sarangi et al. 2017). Note that resistance to *S*-metolachlor has been documented in multiple Palmer amaranth accessions in Arkansas (Brabham et al. 2019). If widespread resistance to *S*-metolachlor is observed in a field of soybeans, the DFF-containing premixture could be a viable alternative option for controlling Palmer amaranth and waterhemp. Overall, the DFF-containing premixture was similar to or more effective at controlling these weeds than the *S*-metolachlor: metribuzin premixture only one site-year where the *S*-metolachlor: metribuzin premixture provided longer residual control of Palmer amaranth and waterhemp.

The flumioxazin:pyroxasulfone:metribuzin premixture is a premium option for preemergence use in soybean because it contains three highly effective herbicides with differing SOAs against Palmer amaranth and waterhemp. Therefore, the DFF-containing premixture was compared against the flumioxazin: pyroxasulfone:metribuzin premixture, with both treatments having a similar number of herbicides and SOAs. Except for Keiser in 2022 and 2023, the DFF-containing premixture was as effective as the flumioxazin:pyroxasulfone:metribuzin premixture at reducing Palmer amaranth and waterhemp through 42 DAT (Tables 4, 5, and 6). Previous research (Sanctis et al. 2021) found that a flumioxazin:pyroxasulfone:metribuzin premixture delayed the critical time of Palmer amaranth removal as much as 45 d after soybean emergence when it was applied preemergence. Through the final evaluation at 56 DAT, Palmer amaranth and waterhemp densities were reduced by more than 93% by the flumioxazin: pyroxasulfone:metribuzin premixture. In other research, flumioxazin plus pyroxasulfone reduced Palmer amaranth density by 93% and 98%, respectively, relative to the nontreated check 28 DAT in 2016 and 2017 (Houston et al. 2021).

The DFF-containing premixture was spiked with additional metribuzin and mixed with dicamba to determine whether it would increase the effectiveness of the herbicide on *Amaranthus* species. Adding metribuzin to the DFF-containing premixture generally did not improve the effectiveness of the herbicide on Palmer amaranth or waterhemp. At only one site-year at 42 DAT, did plots treated with additional metribuzin have fewer Palmer amaranth plants (Table 6). Similarly, adding dicamba to the DFF-containing premixture did not improve herbicide performance on either species in any site year or evaluation timing compared to the premixture alone. The lack of improved suppression of Palmer amaranth and waterhemp emergence with the addition of dicamba is not surprising, considering that the herbicide has a short half-life (17 to 32 d) and readily leaches with minimal rainfall (Altom and

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Table 8. Influence of evaluation timing and herbicide treatments on soybean injury in 2022 at the Keiser, AR, site and 2023 at the Morrice, MI site.[a,b,c]

Treatment	Keiser, AR			Morrice, MI	
	2022			2023	
	14 DAT	28 DAT	42 DAT	28 DAT	35 DAT
	Injury				
	——————————%——————————				
Acetochlor	0 b	4 c	0 c	0 c	0 b
Metribuzin	2 b	20 ab	9 a	0 c	0 b
S-metol. + Met	0 b	10 bc	1 bc	0 c	0 b
DFF premix	28 a	23 ab	5 abc	18 ab	10 a
DFF premix + Met	40 a	37 a	4 abc	21 a	11 a
Flum + Pyro + Met	2 b	12 bc	7 ab	15 b	17 a
DFF premix + Dic	32 a	23 ab	0 c	20 a	11 a
P-value	<0.0001	<0.0001	0.0004	<0.0001	<0.0001

[a]Abbreviations: DAT, days after treatment; Dic, dicamba; DFF premix, diflufenican:metribuzin: flufenacet premixture; Flum, flumioxazin; Met, metribuzin; Pyro, pyroxasulfone; *S*-metol, *S*-metolachlor.
[b]Columns within evaluation timing not containing the same letters are statically different according to Tukey's honestly significant difference test (α = 0.05).
[c]P-values were generated using the glmmTMB function in R Studio software (v. 4.3.2) using a beta distribution.

Stritzke 1973; Harris 1964). In five of six site-years, rainfall greater than 1.5 cm occurred within a 7-d period after planting (data not shown), likely leaching the dicamba from the uppermost depths of the soil profile.

Differing levels of crop response resulted from the various treatments evaluated in Keiser in 2022 and Morice in 2023 (Table 8). All treatments containing diflufenican exhibited the greatest levels of injury through 28 DAT at Keiser and through 35 DAT at Morrice. In general, the herbicide treatments not containing diflufenican were less injurious to soybean and on no occasion were they more injurious. It is important to note soybeans recovered from early-season injury at sites where injury was most prevalent, with less than 8% injury at the Keiser site in 2022 by 42 DAT (Table 8), and no injury at the Morrice site in 2023 by 42 DAT (data not shown). As a result of exceeding the maximum annual use rate of glufosinate in soybean and applications beyond the R1 growth stage, grain yield was not measured; hence, it is unknown whether the early-season injury observed would translate to yield loss.

Practical Implications

The DFF-containing premixture proved highly effective against Palmer amaranth and waterhemp through 28 DAT, providing better than a 96% reduction in the density of both weeds (Table 5). Overlapping of residual herbicides, when a preemergence herbicide is followed by postemergence plus residual herbicides, is a common recommendation for soybean and other agronomic crops (Norsworthy et al. 2012). With the application of preemergence herbicides, the need for in-crop weed removal with a postemergence application that includes a residual herbicide occurs 4 to 6 wk after planting (Knezevic et al. 2019); hence, the DFF-containing premixture appears to maintain a high level of Palmer amaranth and waterhemp control through the normal timing of the postemergence application. At the final evaluation (56 DAT), the density of Palmer amaranth and waterhemp was similar in plots treated with the three-way premium premixture of flumioxazin + pyroxasulfone + metribuzin compared to the DFF-containing premixture. If the DFF-containing premixture is priced lower than the premium three-way mixture product, growers should strongly consider the latter product because there does not appear to be a significant reduction in performance on Palmer amaranth or waterhemp. Another reason for using the DFF-containing premixture is the occurrence of protoporphyrinogen oxidase resistance in Palmer amaranth and waterhemp. There was no known Group 14 resistance at any of the test sites where the trials were conducted, which likely benefited the performance of the flumioxazin-containing premixture.

With the planned introduction of the DFF-containing premixture in the upcoming years, diflufenican will be the first Group 12 herbicide labeled for use in soybean throughout the United States. With the premixture that includes three different SOAs, producers will be able to use multiple effective herbicides to target two of the most resistant-prone and troublesome weeds in U.S. soybean production. Overall, the DFF-containing premixture appears to be highly effective against Palmer amaranth and waterhemp with consistent residual control up to 28 DAT. The DFF premixture appears to be more effective than both single-active-ingredient herbicides evaluated in this study. Additionally, the DFF-containing premixture was superior or comparable to the *S*-metolachlor:metribuzin premixture in five of six site-years. The DFF-containing premixture was never more effective than the flumioxazin:pyroxasulfone:metribuzin premixture; however, similar weed densities were observed in four site-years. The number of weeds was greatly reduced with all the herbicides evaluated relative to the nontreated plots, which are expected to reduce the selection for resistance to postemergence herbicides. Soybean injury >15% was observed from the DFF-containing premixture at 28 DAT; however, it is unknown whether the early-season injury would translate to yield loss. Starting with a strong preemergence herbicide, like the DFF-containing premixture, should be a cornerstone of an effective weed management plan.

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