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Acetochlor; dicamba; diflufenican; flufenacet; glufosinate; glyphosate; metribuzin; annual grasses, *Poaceae* spp.; common lambsquarters, *Chenopodium album* L.; common ragweed, *Ambrosia artemisiifolia* L.; morningglory spp., *Ipomoea* ssp.; Palmer amaranth, *Amaranthus palmeri* (S.) Wats.; prickly sida, *Sida spinosa* L.; soybean; *Glycine max* (L.) Merr

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Performance of a diflufenican-containing premixture in dicamba-resistant soybean systems

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Abstract

Weeds belonging to the *Amaranthus* family are most problematic for soybean producers. With Palmer amaranth evolving resistance to multiple herbicides labeled for use in soybean, producers seek new sites of action to integrate into season-long herbicide programs. Bayer CropScience plans to launch a Convintro™ brand of herbicides, one being a premixture that will include diflufenican (categorized as a Group 12 herbicide by the Weed Science Society of America [WSSA]), metribuzin (WSSA Group 5), and flufenacet (WSSA Group 15), for use preemergence in soybean. Research trials were conducted in Fayetteville and Keiser, AR, and Holt, MI, in 2022 and 2023, to evaluate the premixture in a season-long program in a dicamba-resistant soybean system. A 0.17:0.35:0.48 ratio of a premixture of diflufenican:metribuzin:flufenacet (DFF-containing premixture) was applied preemergence with different combinations of glyphosate, glufosinate, dicamba, and acetochlor at 28 (early postemergence) and 42 (late postermergence) days after planting (DAP). At the early postemergence timing, the DFF-containing premixture provided >90% control of Palmer amaranth and prickly sida. However, common ragweed, common lambsquarters, morningglory ssp., and annual grass control was ≤80% at this timing. When the late postemergence applications occurred, treatments that had already received an early postemergence application controlled prickly sida, morningglory ssp., Palmer amaranth, and annual grasses to a greater extent than those that had not, indicating the preemergence application of the DFF-containing premixture was not sufficient to provide control of the weed spectrum through 42 DAP. By 70 DAP, all programs provided ≥93% control of all weeds evaluated. Herbicide programs that included the DFF-containing premixture preemergence followed by (fb) EPOST fb LPOST common ragweed, common lambsquarters, morningglory ssp., and annual grasses to a greater than the one-pass postemergence systems. In addition, all herbicide programs evaluated in this study reduced Palmer amaranth seed production by >99%. However, producers who plan to use the DFF-containing premixture may need two postemergence herbicide applications to obtain high levels of weed control throughout the growing season.

Introduction

One of the most frequent problems that soybean producers face is control of weeds throughout the growing season. Palmer amaranth, morningglories, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], horseweed [*Conyza canadensis* (L.) Cronquist], common lambsquarters, ragweed species, waterhemp [*Amaranthus tuberculatus* (Moq.) J.D. Sauer, *Amaranthus rudis* Sauer], and kochia (*Bassia scoparia* L.) have been listed as some of the most troublesome weeds in soybean (Van Wychen 2022; Riar et al. 2013). Uncontrolled weeds are detrimental to soybean yields because of competition with the crop for light, water, and nutrients (Regnier and Stoller 1989). For example, Palmer amaranth at a density of one plant per meter of row reduces soybean yields by 32% (Klingaman and Oliver 1994). Similarly, common cocklebur (*Xanthium strumarium* L.) reduces soybean yields by 18% at a density of 3,300 plants ha^{-1} (Barrentine 1974). Due to the potential for weeds to impact yields, production efforts often focus on maintaining a weed-free environment throughout the growing season.

The introduction of the glyphosate-resistant soybean in 1996 quickly shifted management strategies for producers across the United States. Producers rapidly adopted the technology

Table 1. Soil series, texture, organic matter, and pH for the three test locations.[a,c]

	Location					
	Fayetteville, AR		Holt, MI		Keiser, AR[b]	
	2022	2023	2022	2023	2022	2023
Soil series	Captina	Leaf	Conover		Sharkey	
Soil texture	Silt loam		Loam	Sandy clay loam	Clay	
Sand (%)	13	18	45	47	17	17
Silt (%)	74	69	29	23	34	34
Clay (%)	13	13	26	30	49	49
OM (%)	1.8	1.6	2.6	2.9	2.3	2.3
pH	6.5	6.6	6.4	7.3	6.9	6.9

[a]Abbreviations: OM, organic matter.
[b]Trial was conducted in an adjacent field in 2023, and soil texture, OM, and pH were assumed to be similar to 2023.
[c]Soil series and texture were obtained from USDA-NRCS (2024).

Table 2. Dates for planting and herbicide application.

Location	Planting	PRE[a]	EPOST	LPOST
Fayetteville, AR	May 12, 2022	May 13, 2022	June 9, 2022	June 23, 2022
	May 9, 2023	May 10, 2023	June 7, 2023	June 22, 2023
Holt, MI	May 23, 2022	May 23, 2022	June 20, 2022	July 8, 2022
	May 10, 2023	May 10, 2023	June 8, 2023	June 20, 2023
Keiser, AR	May 4, 2022	May 4, 2022	June 2, 2022	June 14, 2022
	May 17, 2023	May 18, 2023	June 13, 2023	June 27, 2023

[a]Abbreviations: EPOST, early postemergence; LPOST, late postemergence; PRE, preemergence.

Table 3. Information for herbicides used in experiments.

Trade name	Herbicide	Manufacturer[a]
Convintro	diflufenican metribuzin flufenacet	Bayer CropScience
Roundup Powermax 3	glyphosate	Bayer CropScience
Interline	glufosinate	UPL
Warrant	acetochlor	Bayer CropScience
Xtendimax with VaporGrip Technology	dicamba	Bayer CropScience

[a]Manufacturer locations: Bayer CropScience, St. Louis, MO; UPL, King of Prussia, PA.

because of economic benefits, production efficiency, and flexibility (Dill 2005). Producers who adopted the glyphosate-resistant technology often ceased using other herbicides, reduced tillage events, and relied almost extensively on applications of glyphosate for in-crop weed control (Powles 2008). Glyphosate was effective against a wide array of weeds and was highly effective against large plants, providing flexibility in the timing of herbicide applications (Dill 2005; Powles 2008). Because of the reduced herbicide diversity and the heavy reliance upon glyphosate for weed control, weeds evolved resistance to the herbicide. More than 55 weeds have evolved resistance to glyphosate globally (Heap 2024), forcing producers to alter their weed management strategies.

With glyphosate not effectively controlling problematic weeds such as Palmer amaranth in soybean, producers began to rely upon other herbicides for in-crop weed control. Previous research has documented that glufosinate plus a preemergence herbicide reduced glyphosate-resistant Palmer amaranth density and seed production by 99% compared to glyphosate alone (Norsworthy et al. 2016). The three most used active ingredients preemergence in soybean across the mid-southern United States are metolachlor, flumioxazin, and metribuzin (Schwartz-Lazaro et al. 2018). In addition to a preemergence application, producers often sequentially apply postemergence herbicides in combination with those that provide residual weed control (Norsworthy et al. 2012). Commercializing new herbicide-resistant technologies allows producers more postemergence options to combat weed resistance. The XtendFlex® technology is one of the latest commercialized technologies, enabling producers to make postemergence applications of glufosinate, glyphosate, and dicamba. Flumioxazin + pyroxasulfone preemergence followed by (fb) *S*-metolachlor + glyphosate + dicamba 6 to 7 wk after a preemergence application controlled Palmer amaranth by 95% at 28 d after the final application (Meyer et al. 2015). However, Palmer amaranth, the most problematic weed in soybean, has evolved resistance to herbicides in Groups 2, 3, 4, 5, 9, 10, 14, 15, and 27 (as categorized by the Weed Science Society of America) (Heap 2024), leaving producers seeking new sites of action to control this and other weeds.

In 2021, Bayer CropScience announced its intentions to launch a Convintro™ brand of herbicides, which will be marketed to control *Amaranthus* species (Anonymous 2021). One of the new herbicides will be a three-way premixture including diflufenican (WSSA Group 12), metribuzin (WSSA Group 5), and flufenacet (WSSA Group 15) for use up to 3 d after planting (DAP) in soybean (A. Mills, Bayer CropScience, personal communication, March 2024). If diflufenican is labeled for use in soybean it would be the first use of a Group 12 herbicide for soybean throughout the United States. Norflurazon, another Group 12 herbicide, is currently labeled for use in soybean production; however, the herbicide is not readily used, with the label restricting use to the mid-southern United States (Anonymous 2015). Therefore, if

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Table 4. Herbicide treatment, timing, and rate for the various programs evaluated in the study.[a,c]

Herbicide treatment	Timing	Rate [b]
		g ai/ae ha^{-1}
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	28 DAP	1,550
Glufosinate	28 DAP	660
Acetochlor	28 DAP	1,260
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	28 DAP	1,550
Dicamba	28 DAP	560
Acetochlor	28DAP	1,260
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	42 DAP	1,550
Glufosinate	42 DAP	660
Acetochlor	42 DAP	1,260
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	42 DAP	1,550
Dicamba	42 DAP	560
Acetochlor	42 DAP	1,260
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	28 DAP	1,550
Glufosinate	28 DAP	660
Glyphosate	42 DAP	1,550
Glufosinate	42 DAP	660
Acetochlor	42 DAP	1260
Diflufenican	PRE	120, 150, 180
Metribuzin	PRE	240, 300, 360
Flufenacet	PRE	330, 410, 490
Glyphosate	28 DAP	1,550
Dicamba	28 DAP	560
Glyphosate	42 DAP	1,550
Dicamba	42 DAP	560
Acetochlor	42 DAP	1,260

[a]Abbreviations: DAP, days after planting; PRE, preemergence.
[b]The first rate of the diflufenican:metribuzin:flufenacet listed is for a silt loam soil, the second rate is for a loam and a sandy clay loam soil with >1.5% organic matter, and the third rate is for a clay soil >1.5% organic matter.
[c]Dicamba treatments included VaporGrip at 1.5 L ha^{-1} and intact at 0.29 L ha^{-1}.

Table 5. Weed species, average density, and average height at EPOST and LPOST in nontreated plots at the three experimental locations in 2022 and 2023.[a,b,c]

Location	Timing	Year	Weed species	Density	Height
				m^{-2}	cm
Fayetteville, AR	EPOST	2022	AMAPA	30	5.1
			BRAPP	19	5.1
			IPOHG	4	2.5
Fayetteville, AR	LPOST	2022	AMAPA	30	17.8
			BRAPP	4	1.3
			IPOHG	4	12.7
Fayetteville, AR	EPOST	2023	AMAPA	6	10.2
			BRAPP	5	7.6
Fayetteville, AR	LPOST	2023	AMAPA	7	30.5
			BRAPP	10	12.7
Keiser, AR	EPOST	2022	AMAPA	5	10.2
			CONSS	3	5.1
			ECHSS	4	10.2
			SIDSP	10	7.6
Keiser, AR	LPOST	2022	AMAPA	10	15.2
			CONSS	4	15.2
			ECHSS	8	25.4
			SIDSP	16	15.2
Keiser, AR	EPOST	2023	AMAPA	3	7.6
			CONSS	3	7.6
			ECHSS	12	7.6
			SIDSP	4	5.1
Keiser, AR	LPOST	2023	AMAPA	5	15.2
			CONSS	2	15.2
			ECHSS	10	25.4
			SIDSP	4	20.3
Holt, MI	EPOST	2022	AMBEL	11	10.2
			ANGR	22	7.6
			CHEAL	32	7.6
Holt, MI	EPOST	2023	AMBEL	32	7.6
			ANGR	86	10.2
			CHEAL	54	7.6
Holt, MI	LPOST	2023	AMBEL	–	12.7
			ANGR	–	15.2
			CHEAL	–	10.2

[a]Abbreviations: AMAPA, Palmer amaranth; AMBEL, common ragweed; ANGR, annual grasses; BRAPP, broadleaf signalgrass; CHEAL, common lambsquarters; CONSS, morningglory species; ECHSS, barnyardgrass; EPOST, early postemergence; IPOHG, entireleaf morningglory; LPOST, late postemergence; SIDSP, prickly sida.
[b]Weed species and density were not collected in Michigan at LPOST in 2022.
[c]Weed densities were not collected in Michigan at LPOST in 2023.

labeled Convintro will offer a new site of action for weed control in soybean.

Diflufenican is not a new herbicide; it has been used extensively preemergence and early postemergence in European cereal production (Cramp et al. 1987). When applied preemergence to wheat (*Triticum aestivum* L.), diflufenican was highly effective against broadleaf weed species; however, producers should not expect control of other weed species (Haynes and Kirkwood 1992). Due to the limited spectrum of diflufenican, it is typically paired with an additional herbicide such as flufenacet, a labeled premixture in Europe (Anonymous 2020). The combination of diflufenican + flufenacet provided >90% control of blackgrass (*Alopecurus myosuroides* Huds.), a problematic weed in wheat (Bailly et al. 2012).

The objective of this research is to understand the spectrum of weed control provided by a premixture of diflufenican:metribuzin:flufenacet (hereafter referred to as DFF-containing premixture) and determine whether producers can use a one-pass postemergence system or if sequential postemergence applications will be needed to obtain adequate weed control when the DFF-containing premixture is applied at soybean planting.

Material and Methods

Field experiments were conducted in 2022 and 2023 at the Milo J. Shult Agriculture Research and Extension Center in Fayetteville, AR (36.0968°N 94.17451°W), the Michigan State University Horticulture Teaching and Research Center in Holt, MI (42.67638°N 84.4875°W), and the Northeast Arkansas Research and Extension Center in Keiser, AR (35.67613°N 90.08517°W) (Table 1). The seedbed was prepared at all locations using conventional tillage, including disk and cultivation and chisel plowing in Michigan. In addition, beds were pulled before planting at all Arkansas locations. Following ground preparation, soybean cultivar 'AG26XF3' (Bayer CropScience, St. Louis, MO) was planted at 370,000 seeds ha^{-1} into four-row plots (76-cm spacing) measuring 9.1 m in length at the Holt location. At both Arkansas locations soybean cultivar 'AG45XF0' (Bayer CropScience) was planted at 346,000 seeds ha^{-1} into four-row plots measuring 7.6 m in length. Plot width at the Fayetteville location was 3.7 m (91-cm

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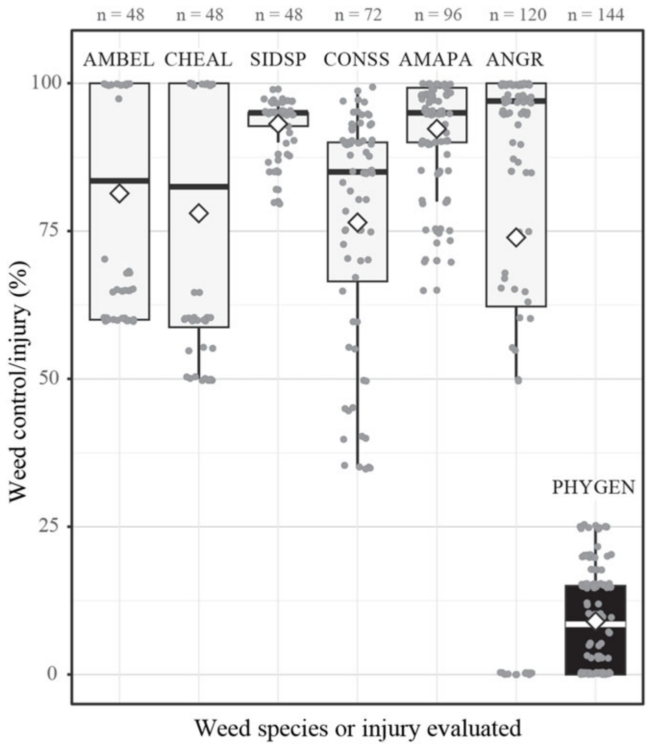

Figure 1. Box and whisker plots depicting average injury (PHYGEN) and common ragweed (AMBEL), common lambsquarters (CHEAL), prickly sida (SIDSP), morningglory species (CONSS), Palmer amaranth (AMAPA), and annual grasses (ANGR) control from the preemergence applied diflufenican:metribuzin:flufenacet premixture 28 d after planting. Morningglory species consisted of pitted and entireleaf. Annual grasses consisted of foxtails, broadleaf signalgrass, and barnyardgrass.

spacing), and 3.9 m at the Keiser location (97-cm spacing). Preplant fertilizer was applied when needed based on soil test results for each location based on University of Arkansas and Michigan State University recommendations for soybean (Ross et al. 2022; Warncke et al. 2009). Furrow or overhead irrigation occurred if 2.5 cm rainfall did not occur within a 7-d period for trials conducted in Arkansas. Trials in Michigan were conducted under nonirrigated conditions, which is typical of soybean production in that region.

The experiment was designed as a randomized complete block with four replications and one factor (herbicide program). Herbicide applications occurred preemergence, early postemergence (28 DAP), and late postemergence (42 DAP) (Table 2), consisted of the DFF-containing premixture followed by various combinations of dicamba, glyphosate, glufosinate, and acetochlor (Table 3). Six different herbicide programs were evaluated, with herbicide rates adjusted for the soil texture at each location (Table 4). At the Arkansas locations, herbicides were applied using a CO_2-pressurized backpack sprayer and a four-nozzle boom calibrated to deliver 140 L ha^{-1} at 4.8 km h^{-1} using AIXR 110015 nozzles (TeeJet Technologies, Glendale Heights, IL), except for postemergence treatments that contained dicamba. Herbicide treatments that contained dicamba were applied using TeeJet TTI 110015 nozzles. In Michigan, herbicides were applied using a tractor-mounted sprayer calibrated to deliver 178 L ha^{-1} at 6.1 km h^{-1} using TeeJet AIXR 11003 nozzles for preemergence and TeeJet TTI 11003nozzles for postemergence treatments.

Data Collection

Visible weed control ratings were estimated on a scale of 0% to 100%, with 0% being no weed control and 100% being complete weed control 28, 42 (excluding Holt, MI in 2023), 56, and 70 DAP for the weed spectrums present at each location (Table 5) (Frans and Talbert 1977). In addition, soybean injury evaluations were collected at 28 DAP, prior to the early postemergence application. Before harvest, weed biomass was collected from two 0.5-m^{-2} quadrats at both Arkansas locations in 2022 and 2023. Biomass was collected by cutting weeds at the soil surface and grouping them into bags by species. Palmer amaranth was sorted by gender to obtain an estimate of seed production, and any additional weeds were grouped and referred to as "other weeds". All harvested plant material was placed into an oven at 66 C for 2 wk, and dry biomass was recorded. Female Palmer amaranth plants were then threshed, and seeds were separated from any remaining plant material by using a 20-mesh sieve followed by a vertical air column seed cleaner (Seedburo Equipment Company, Des Plaines, IL) (Miranda et al. 2021). After cleaning, three 200-seed samples were collected and weighed from each Arkansas location. The average weights were then used to estimate seed production of surviving Palmer amaranth plants. Finally, soybean grain was collected using a small-plot combine and adjusted to 13% moisture. Only the two center rows of each plot were harvested at each location.

Data Analysis

Statistical analysis was performed using the *glmmTMB* function in R studio software (v. 4.3.2; R Core Team 2022) (GLMMTMB package; Brooks et al. 2017). Control of common lambsquarters, common ragweed, morningglory species, prickly sida, Palmer amaranth, annual grasses, weed biomass, and grain yield were fitted to a generalized linear mixed-effect model (GLMM) by evaluation timing (Stroup 2015). Herbicide program was considered a fixed effect, and replication nested within location was considered random. All control data were bound between 0 and 1 and analyzed using a beta distribution (Gbur et al. 2012). After the residuals failed to violate the Shapiro-Wilks normality test, weed biomass and grain yield were analyzed using a Gaussian or normal distribution. Analysis of variance was performed on each fitted model using the CAR package (Fox and Weisberg 2019) with Type III Wald chi-square test. Estimated marginal means (Searle et al. 1980) for herbicide programs were obtained using the EMMEANS package (Lenth 2022). The Sidak method was used to adjust for multiple comparisons (Midway et al. 2020) and a compact letter display was generated using the MULTCOMP package (Hothorn et al. 2008) to visually represent significantly different groups. Orthogonal contrasts were used to determine whether an early postemergence application was more effective than no early postemergence application, and whether there was a difference between glyphosate + dicamba compared to glyphosate + glufosinate 42 DAP. Additionally, contrasts were used to determine whether multiple sequential postemergence applications were more effective than a single postemergence application, and whether there was a difference in weed control when waiting until 28 DAP to apply the postemergence herbicide compared with waiting until 42 DAP.

Table 6. Influence of various herbicide programs following a preemergence application of a diflufenican:metribuzin:flufenacet premixture 42 DAP.[a–e]

Herbicide treatment	Timing	Control					
		AMBEL	CHEAL	SIDSP	CONSS[f]	AMAPA	ANGR[g]
		%					
Glyphosate +	28 DAP	100	100	95 a	91 a	99 a	99 a
Glufosinate +	28 DAP						
Acetochor	28 DAP						
Dicamba +	28 DAP	100	100	97 a	91 a	99 a	98 a
Glyphosate +	28 DAP						
Acetochlor	28 DAP						
Glyphosate +	42 DAP	100	100	83 b	72 b	89 b	84 b
Glufosinate +	42 DAP						
Acetochor	42 DAP						
Dicamba +	42 DAP	100	100	80 b	56 b	84 c	86 b
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
Glyphosate +	28 DAP	100	100	96 a	89 a	98 a	98 a
Glufosinate	28 DAP						
Glyphosate +	42 DAP						
Glufosinate +	42 DAP						
Acetochor	42 DAP						
Dicamba +	28 DAP	100	100	95 a	92 a	99 a	98 a
Glyphosate	28 DAP						
Dicamba +	42 DAP						
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
P-value		1.000	1.000	<0.001	<0.001	<0.001	<0.001
EPOST vs. no EPOST[h]		100 vs. 100 NS	100 vs. 100 NS	96 vs. 82***	91 vs. 64***	99 vs. 87***	98 vs. 84***
Dicamba + glyphosate vs. Glyphosate + glufosinate		100 vs. 100 NS	100 vs. 100 NS	96 vs. 96 NS	92 vs. 90 NS	99 vs. 99 NS	99 vs. 98 NS

[a]Abbreviations: AMAPA, Palmer amaranth; AMBEL, common ragweed; ANGR, annual grasses; CHEAL, common lambsquarters; CONSS, morningglory ssp.; DAP, days after planting; EPOST, early postemergence; SIDSP, prickly sida.
[b]Evaluations include common ragweed, common lambsquarters, prickly sida, morningglory, Palmer amaranth, and annual grass control as well as contrasts from an EPOST application or not and dicamba + glyphosate vs. glufosinate + glyphosate.
[c]All herbicide programs included diflufenican:metribuzin:flufenacet premixture applied preemergence.
[d]Means within a column followed by the same letter are not different according to the Sidak method ($\alpha = 0.05$).
[e]Site years: AMBEL, Holt 2022; CHEAL, Holt 2022; SIDSP, Keiser 2022 and 2023; CONSS, Fayetteville 2022, Keiser 2022 and 2023; AMAPA, Fayetteville 2022 and 2023, Keiser 2022 and 2023; ANGR, Holt 2022, Fayetteville 2022 and 2023, Keiser 2023.
[f]Morningglory species included pitted morningglory and entireleaf morningglory.
[g]Annual grasses included foxtails, broadleaf signalgrass, and barnyardgrass.
[h]Asterisks are used to indicate contrasts as follows: *, significant ($P < 0.05$); **, significant ($P < 0.01$); ***, significant ($P < 0.001$); NS, nonsignificant ($P \geq 0.05$).

Results and Discussion

The DFF-containing premixture was applied preemergence for all the herbicide programs, which gave an indication of injury and control spectrum against various weeds (Table 5). Soybean injury from the DFF-containing premixture ranged from 0% to 25% by 28 DAT (Figure 1). The higher soybean injury is likely attributed to significant rainfall events that occurred soon after planting, which is consistent with previous research when greater injury from diflufenican or the DFF-containing premixture was observed when high rainfall amounts, or soil moisture occurs (Laplante 2022; Woolard et al. 2024). The variability of control from the DFF-containing premixture was least for Palmer amaranth and prickly sida, with average control >90% for both weeds 28 DAP (Figure 1). In other research, flumioxazin + pyroxasulfone, *S*-metolachlor + isoxaflutole + metribuzin, dicamba + acetochlor, *S*-metolachlor + mesotrione + metribuzin, and *S*-metolachlor + fomesafen + metribuzin combinations applied preemergence controlled Palmer amaranth ≥95% for 3 to 4 wk (Meyer et al. 2015). Control of morningglory ssp. averaged 75%; however, control levels <40% occurred. The lack of effective control was not surprising because in other research the combination of flufenacet + metribuzin at 0.69 and 0.17 kg ha^{-1} applied preemergence controlled pitted morningglory by 59% and 89% across two site-years 4 wk prior to harvest (Grichar et al. 2003). Furthermore, metribuzin is not an effective option for controlling entireleaf morningglory (Barber et al. 2024), which comprised the morningglory specie at the research sites in Arkansas. Therefore, producers should not expect consistent satisfactory control of morningglory ssp. if the DFF-containing premixture is applied preemergence.

The DFF-containing premixture controlled common ragweed, common lambsquarters, and annual grasses on average 74% to 85%, but the level of control was highly variable. At the Michigan sites, differences in rainfall occurred between 2022 and 2023. In 2022, 12.7 cm of rainfall occurred in May and June; however, just 4.5 cm of rainfall occurred in the same period in 2023 (data not shown). While annual grasses were evaluated at other sites, the high variability in control of the weed as well as common lambsquarters and common ragweed, could be attributed to the drastic differences in rainfall or lack of activation in Michigan in 2023. Diflufenican and metribuzin are excellent preemergence options for control of broadleaf weed species (Haynes and Kirkwood 1992; Barber et al. 2024); however, producers should not expect satisfactory control of annual grasses. The control of annual grasses with the DFF-containing premixture can be attributed to flufenacet, since the herbicide is labeled for control of all annual grasses evaluated at Arkansas and Michigan locations (Anonymous 2007). Overall, the DFF-containing

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Table 7. Influence of various herbicide programs following a preemergence application of a diflufenican:metribuzin:flufenacet premixture 56 DAP.[a–e]

		Control					
Herbicide treatment	Timing	AMBEL	CHEAL	SIDSP	CONSS[f]	AMAPA	ANGR[g]
		%					
Glyphosate +	28 DAP	97 c	96 d	95 ab	92	95 ab	98 bc
Glufosinate +	28 DAP						
Acetochlor	28 DAP						
Dicamba +	28 DAP	100 a	99 b	92 b	91	92 b	97 c
Glyphosate +	28 DAP						
Acetochlor	28 DAP						
Glyphosate +	42 DAP	95 c	96 d	98 a	91	98 a	98 bc
Glufosinate +	42 DAP						
Acetochor	42 DAP						
Dicamba +	42 DAP	96 c	98 c	98 a	93	98 a	98 bc
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
Glyphosate +	28 DAP	99 b	100 a	96 ab	93	96 ab	100 a
Glufosinate	28 DAP						
Glyphosate +	42 DAP						
Glufosinate +	42 DAP						
Acetochor	42 DAP						
Dicamba +	28 DAP	100 a	100 a	98 a	95	98 a	99 ab
Glyphosate	28 DAP						
Dicamba +	42 DAP						
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
P-value		<0.001	<0.001	<0.001	0.668	<0.001	<0.0001

[a]Abbreviations: AMAPA, Palmer amaranth; AMBEL, common ragweed; ANGR, annual grasses; CHEAL, common lambsquarters; CONSS, morningglory ssp.; DAP, days after planting; SIDSP, prickly sida.
[b]Evaluations included common ragweed, common lambsquarters, prickly sida, morningglory, Palmer amaranth, and annual grass control.
[c]The diflufenican:metrbuzin:flufenacet premixture was applied preemergence as part of all herbicide programs.
[d]Means within a column followed by the same letter are not different according to the Sidak method ($\alpha = 0.05$).
[e]Site-years: AMBEL, Holt, MI, 2022 and 2023; CHEAL, Holt 2022 and 2023; SIDSP, Keiser, AR, 2022 and 2023; CONSS, Fayetteville, AR, 2022, Keiser 2022 and 2023; AMAPA, Fayetteville 2022 and 2023, Keiser 2022 and 2023; ANGR, Holt 2022 and 2023, Fayetteville 2022 and 2023, Keiser 2022 and 2023
[f]Morningglory species included pitted morningglory and entireleaf morningglory.
[g]Annual grasses included foxtails, broadleaf signalgrass, and barnyardgrass.

premixture controlled all weeds evaluated in this study on average ≥74%; however, it was the most variable on annual grasses and morningglory species.

Contrasts reveal that prickly sida, morningglory ssp., Palmer amaranth, and annual grass control improved with an early postemergence application compared to treatments that had not yet received a postemergence application by 42 DAP (Table 6). However, the average control of all weeds following the DFF-containing premixture alone at 42 DAP was >80%, except morningglory species. In addition, contrasts show that weed control did not differ between dicamba + glyphosate or glyphosate + glufosinate applied postemergence when using the DFF-containing premixture preemergence. In other research, no differences in common ragweed, common lambsquarters, Powell amaranth [*Amaranthus powellii* (S.) Wats.], and annual grass control occurred from postemergence applications of dicamba + glyphosate and glyphosate + glufosinate at 14 DAT (Constine 2021).

Of the different herbicide programs evaluated in this study, all the weed species were controlled by >90% 56 DAP (Table 7). A similar trend occurred at 70 DAP (4 wk after late postemergence), providing ≥93% control for all herbicide programs (Table 8). Contrasts indicate that weed control for programs that had the DFF-containing premixture applied preemergence fb early postemergence herbicides fb late postemergence herbicides provided greater control of common ragweed, common lambsquarters, prickly sida, and annual grasses than the premixture applied preemergence fb one postemergence application (early postemergence or late postemergence). In addition, late postemergence applications were more effective in controlling prickly sida and morningglory ssp. than the early postemergence applications, which could be attributed to acetochlor not providing residual control of the weeds mentioned above and subsequent emergence after the early postemergence application. A similar study that assessed different herbicide programs that consisted of a preemergence fb an early postemergence or a late postemergence application found that late postemergence applications provided greater control of Palmer amaranth and waterhemp compared to an early postemergence application 3 to 4 wk after the final application because of a wide emergence period for both weeds (Meyer et al. 2015). While a preemergence application fb a late postemergence application achieved >93% weed control in this study, producers who delay an application to the late postemergence timing will be spraying weeds that are larger in size. Not surprisingly, all weeds were larger at the late postemergence timing compared with early postemergence; however, the size of the weeds in treated plots would be smaller at late postemergence relative to the nontreated plants due to the delayed emergence from the preemergence application (Table 5).

Although Palmer amaranth at the test sites was known to be resistant only to glyphosate and WSSA Group 2 herbicides, the weed has evolved resistance to all postemergence herbicides evaluated in this study (Heap 2024), meaning that producers may not be able to control some populations when using the programs evaluated here. Subsequently, the critical weed-free period for soybean is from V3 to R1 to prevent a yield reduction of 2.5% (Van Acker et al. 1993). If a producer uses the DFF-containing

Table 8. Influence of various herbicide programs following a preemergence application of a diflufenican:metribuzin:flufenacet premixture 70 DAP.[a–e]

Herbicide treatment	Timing	Control					
		AMBEL	CHEAL	SIDSP	CONSS[f]	AMAPA	ANGR[g]
		%					
Glyphosate +	28 DAP	96 c	93 c	98 ab	94 b	97	98 ab
Glufosinate +	28 DAP						
Acetochlor	28 DAP						
Dicamba +	28 DAP	99 b	98 ab	96 b	94 b	97	96 b
Glyphosate +	28 DAP						
Acetochlor	28 DAP						
Glyphosate +	42 DAP	95 c	93 c	98 ab	95 ab	98	98 ab
Glufosinate +	42 DAP						
Acetochlor	42 DAP						
Dicamba +	42 DAP	98 b	99 ab	97 ab	96 ab	97	97 ab
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
Glyphosate +	28 DAP	97 c	97 bc	99 a	95 ab	98	99 a
Glufosinate	28 DAP						
Glyphosate +	42 DAP						
Glufosinate +	42 DAP						
Acetochlor	42 DAP						
Dicamba +	28 DAP	99 a	99 a	98 ab	97 a	98	98 ab
Glyphosate	28 DAP						
Dicamba +	42 DAP						
Glyphosate +	42 DAP						
Acetochlor	42 DAP						
P-value		<0.001	<0.001	0.008	0.010	0.535	0.018
Contrasts[h]							
No Seq vs. Seq		97 vs. 98***	96 vs. 98**	97 vs. 99 NS	95 vs. 96*	97 vs. 98 NS	97 vs. 99*
28 DAP vs. 42 DAP		98 vs. 97 NS	96 vs. 96 NS	97 vs. 98**	94 vs. 96*	98 vs. 97 NS	97 vs. 98 NS

[a]Abbreviations: AMAPA, Palmer amaranth; AMBEL, common ragweed; ANGR, annual grasses; CHEAL, common lambsquarters; CONSS, morningglory ssp.; DAP, days after planting; Seq, sequential application; SIDSP, prickly sida.
[b]Evaluations included common ragweed, common lambsquarters, prickly sida, morningglory, Palmer amaranth, and annual grasses control.
[c]All herbicide programs had the diflufenican:metrbuzin:flufenacet premixture applied preemergence.
[d]Means within a column followed by the same letter are not different according to the Sidak method ($\alpha = 0.05$).
[e]Site years: AMBEL, Holt, MI, 2022 and 2023; CHEAL, Holt 2022 and 2023; SIDSP, Keiser, AR, 2022 and 2023; CONSS, Fayetteville, AR, 2022, Keiser 2022 and 2023; AMAPA, Fayetteville 2022 and 2023, Keiser 2022 and 2023; ANGR, Holt 2022 and 2023, Fayetteville 2022 and 2023, Keiser 2022 and 2023.
[f]Morningglory species included pitted morningglory and entireleaf morningglory.
[g]Annual grasses included foxtails, broadleaf signalgrass, and barnyardgrass.
[h]Asterisks are used to indicate contrasts as follows: *, significant ($P < 0.05$); **, significant ($P < 0.01$); ***, significant ($P < 0.001$); NS, nonsignificant ($P \geq 0.05$).

premixture preemergence and does not make a subsequent application until late postemergence at 42 DAP, weeds could be present during the critical weed-free period, potentially leading to yield reductions considering application typically occurred V6 to R1 (data not shown). Soybean producers who use the DFF-containing premixture will not be able to utilize a single-pass postemergence program seeing as treatments in which two postemergence applications occurred provided greater control on four of the six weeds evaluated at 70 DAT.

At harvest, Palmer amaranth biomass and that of other weeds was reduced by >99% relative to the nontreated check (Table 9). Consequently, all herbicide programs reduced seed production by >99%. While seed production was drastically reduced, the return of Palmer amaranth seeds to the soil seedbank occurred in all programs, except the DFF-containing premixture applied preemergence fb dicamba + glyphosate + acetochlor late postemergence and the DFF-containing premixture preemergence fb glyphosate + glufosinate early postemergence fb glyphosate + glufosinate + acetochlor late postemergence. Escaped Palmer amaranth plants existed in plots that received the DFF-containing premixture preemergence fb dicamba + glyphosate + acetochlor applied late postemergence, but those plants were male, and hence, no seed was produced. Conversely, no Palmer amaranth plants were present at harvest in plots that received the DFF-containing premixture fb sequential applications early postemergence and late postemergence of glyphosate and glufosinate. Due to the evolution of weed resistance to herbicides in soybean, one of the best management strategies to combat these weeds is to reduce seed return to the soil seedbank (Norsworthy et al. 2012). Therefore, producers should exhaust all efforts to prevent problematic weeds such as Palmer amaranth from producing seeds that persist and are problematic in subsequent growing seasons. While differences in weed control occurred throughout the growing season, no differences in soybean grain yields resulted following the different herbicide programs evaluated in this study (Table 9).

Practical Implications

For producers who have Palmer amaranth that is resistant to Group 14 and Group 15 herbicides, the DFF-containing premixture will be a viable option to integrate into a season-long herbicide program. The DFF-containing premixture appears to be highly effective against prickly sida, Palmer amaranth, annual grasses, common lambsquarters, and common ragweed up to 28 DAP, contingent upon the herbicide being activated soon after application. A lack of consistent and effective control of morningglory spp. appears to be a weakness of the DFF-containing premixture. For soybean producers who plan to use the DFF-

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Table 9. Influence of different herbicide programs following a preemergence application of a diflufenican:metribuzin:flufenacet premixture on end of season evaluations.[a–e]

		Seed production	Biomass		
Herbicide treatment	Timing	AMAPA	AMAPA	Other[f]	Yield
		Seed m^{-2}	g	g	kg ha^{-1}
Nontreated	–	104,120 a (0.0)	644.74 a (0.0)	152.41 a (0.0)	2,070 b
Glyphosate +	28 DAP	9 b (99.9)	0.05 b (99.9)	0.06 b (99.9)	4,160 a
Glufosinate +	28 DAP				
Acetochlor	28 DAP				
Dicamba +	28 DAP	22 b (99.9)	0.09 b (99.9)	0.09 b (99.9)	4,060 a
Glyphosate +	28 DAP				
Acetochlor	28 DAP				
Glyphosate +	42 DAP	131 b (99.8)	0.93 b (99.8)	0.02 b (99.9)	4,060 a
Glufosinate +	42 DAP				
Acetochor	42 DAP				
Dicamba +	42 DAP	0 b (100)	0.02 b (99.9)	0.05 b (99.9)	4,060 a
Glyphosate +	42 DAP				
Acetochlor	42 DAP				
Glyphosate +	28 DAP	0 b (100)	0.00 b (100)	0.00 b (100)	4,190 a
Glufosinate	28 DAP				
Glyphosate +	42 DAP				
Glufosinate +	42 DAP				
Acetochor	42 DAP				
Dicamba +	28 DAP	21 b (99.9)	0.05 b (99.9)	0.02 b (99.9)	4,100 a
Glyphosate	28 DAP				
Dicamba +	42 DAP				
Glyphosate +	42 DAP				
Acetochlor	42 DAP				
P-value		0.002	<0.001	<0.001	<0.001

[a]Abbreviations: AMAPA, Palmer amaranth; DAP, days after planting.
[b]Evaluations included Palmer amaranth seed production in 2022 and 2023 at Arkansas sites, biomass of other weeds and Palmer amaranth, and grain yield.
[c]All herbicide programs had the diflufenican:metrbuzin:flufenacet premixture applied preemergence.
[d]Means within a column followed by the same letter are not different according to the Sidak method ($\alpha = 0.05$).
[e]Numbers in parentheses represent percent reduction relative to the nontreated check.
[f]Other weeds consisted of prickly sida, barnyardgrass, broadleaf signalgrass, and morningglory species.

containing premixture, two additional postemergence applications in combination with soil residuals should be used to achieve season-long weed control. To help preserve the longevity of the DFF-containing premixture, producers should strive to minimize weed seed production and use diverse tactics other than relying solely on herbicides to control other troublesome weeds in soybean fields (Norsworthy et al. 2012).

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