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Influence of Application Timing and Cultivar on Soybean Tolerance and Weed Control from Diflufenican or a Diflufenican-Containing Premixture

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Abstract

Bayer CropScience anticipates launching several premixtures for use in soybean, targeted at control of Palmer amaranth. One of the premixtures will contain diflufenican (WSSA Group 12), metribuzin (Group 5), and flufenacet (Group 15) (DFF-containing premixture), offering an alternative site of action for soybean producers. Field experiments were conducted in Arkansas and Michigan to evaluate application timings of the DFF-containing premixture for soybean tolerance and weed control and possible cultivar tolerance differences to diflufenican and the DFF-containing premixture. Soybean injury from the 1X and 2X rates of the DFF-containing premixture ranged from 0% to 60% 14 d after planting (DAP), with injury increasing the closer the herbicide was applied to soybean emergence. Excluding the 2X rate applied 3 DAP in Arkansas in 2023, soybean injury was <20% regardless of location, site year, application timing, and rate. For weed control experiments, only a 1X rate of the DFF-containing premixture was applied at the various application timings. Control of five weed species, encompassing broadleaves and grasses, ranged from 81% to 98%, regardless of application timing by 28 DAP. By 42 DAP, weed control ranged from 71% to 97%, with the 14-d preplant application timing typically being the least effective. The DFF-containing premixture and diflufenican alone were applied PRE at 1X and 2X rates for the soybean cultivar study. Soybean metribuzin sensitivity did not affect the degree of crop response, even on a high pH soil, and injury to soybean never exceeded 20%. Overall, the DFF-containing premixture will be a tool that soybean producers can integrate into a season-long herbicide program for use across the United States regardless of the soybean cultivar.

Nomenclature: Diflufenican; metribuzin; flufenacet; Palmer amaranth, *Amaranthus palmeri* (S.) Wats; soybean, *Glycine max* (L.) Merr

Key words: Convintro, group 12, resistance management

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Introduction

In 2021, Bayer CropScience announced its intentions to launch a Convintro™ brand of herbicides, one being a premixture targeted for use in soybean (Anonymous 2021). The premixture will include diflufenican (WSSA Group 12), metribuzin (WSSA Group 5), and flufenacet (WSSA Group 15) for use preplant up to 3 d after planting (DAP). Flumioxazin, metribuzin, and metolachlor rank among the top three most-used active ingredients preemergence (PRE) in soybean (Schwartz-Lazaro et al. 2018). In addition, WSSA Groups 2 and 3 are alternative sites of action (SOA) recommended for use PRE in soybean (Barber et al. 2024). Norflurazon, another Group 12 herbicide, is sold under the trade name Solicam® DF and is labeled for use in soybean (Anonymous 2015). However, it is priced for the ornamental market and is restricted to use in the mid-southern United States; therefore, the herbicide is not used in soybean production. If labeled, diflufenican will add a new SOA labeled for use in soybean throughout the United States.

Diflufenican was originally discovered in 1979 and commercialized in the 1980s for use in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) production in Europe (Haynes and Kirkwood 1992). Diflufenican provides effective residual control of broadleaf weed species, leading to wide adoption of the herbicide for use PRE in cereal production in Europe (Cramp et al. 1987). Due to the herbicide selectivity, diflufenican is typically paired with other herbicides, such as flufenacet (Anonymous 2020), for broad-spectrum weed control. In the United States, diflufenican is being commercialized to control *Amaranthus* ssp. (Anonymous 2021). Palmer amaranth ranks as the most problematic weed soybean producers face annually (Van Wychen 2022). Yield reductions of up to 17% have occurred from a density as low as 0.33 Palmer amaranth plants per m^{-1} of row in soybean (Klingaman and Oliver 1994). Palmer amaranth has evolved resistance to nine different SOA, including Groups 2, 3, 4, 5, 9, 10, 14, 15, and 27, leaving limited options for producers PRE.

Previous research has evaluated diflufenican alone and the potential factors contributing to soybean injury. Up to 50% injury has occurred from diflufenican at 360 g ai ha^{-1}, 7 d after emergence (DAE), with greater soybean response occurring when the herbicide was applied three to four d after planting compared to a preplant application (Laplante 2022). Similar results have been observed for metribuzin at 0.6 or 1.1 kg ha^{-1}, with applications occurring three weeks before planting, resulting in less soybean injury than PRE applications (Moshier and Russ 1981). Additionally, greater crop response to diflufenican was observed in Canada for early planted soybean (May 20th or 31st 2020) compared to later planting dates (June 9th 2020) in which rainfall amounts impacted soybean injury (Laplante 2022). Injury to soybean in 2020 ranged from 3% to 42% when rainfall occurred 1 to 3 d after emergence for an early or mid-May planting; however, the injury never exceeded 15% when the crop was planted in mid-June, and minor rainfall events occurred 7 DAE (Laplante 2022). Currently, soybeans are planted in early to mid-May to maximize yield potential in Arkansas and Michigan (Singh 2022; Ross et al. 2022).

With the application timing of the diflufenican:metribuzin:flufenacet premixture ranging from preplant (PP) to 3 DAP, one potential concern is the length of residual control if a producer utilizes the herbicide preplant compared to a PRE application. Palmer amaranth emergence following soybean planting was lower for PP applications of commonly used herbicides than for a PRE application through 28 d after planting (DAP) (Priess et al. 2020). However, Palmer amaranth emergence was greater for all herbicide combinations evaluated, except *S*-metolachlor + metribuzin, when applied PP compared to PRE applications in another year, likely because of rainfall differences for activation. Applying a herbicide PP increases the likelihood of rainfall activation; however, rainfall amounts can dictate the persistence of a particular herbicide and the associated weed control (Oliver et al. 1993).

Metribuzin ranks among the top three PRE-applied herbicides in soybean (Schwartz-Lazaro et al. 2018) and effectively controls Palmer amaranth (Whitaker et al. 2010); hence, it is utilized as a component of the DFF-containing premixture. However, soybean cultivars differ in tolerance to metribuzin. Several factors, including metribuzin rate, cultivar, soil texture, soil pH, soil organic matter, and amount of rainfall or overhead irrigation, impact the extent of metribuzin injury on soybean (Coble and Schrader 1973; Hardcastle 1974; Ladlie et al. 1976; Smith and Wilkinson 1974). Previous research has documented that the number of soybean plants killed increased, and plant height decreased as soil pH increased (Ladlie et al. 1976); hence, the herbicide is not recommended when soil pH is 7.5 or higher (Anonymous 2014). Metribuzin is not recommended on sandy, sandy loam, or loamy sands with less than 2% organic matter (Barber et al. 2024). The typically recommended use rate for metribuzin in soybean is 420 to

1,120 g ai ha^{-1}, respectively, depending on soil texture (Anonymous 2014); however, the metribuzin ratio in the DFF-containing premixture is such that the metribuzin rate will be lower than when the herbicide is applied as a stand-alone product.

The objective of this research was to evaluate different application timings and rates of the diflufenican:metribuzin:flufenacet premixture (which will be referred to as the DFF-containing premixture throughout the remainder of the paper) for soybean tolerance, determine if application timings of the DFF-containing premixture influence weed control and, lastly, to determine if the addition of metribuzin to the DFF-containing premixture increases injury for metribuzin-sensitive cultivars on a high pH soil compared to diflufenican alone.

Material and Methods

Common methodology

The soil seedbed was prepared using conventional tillage, which included disking and cultivation at all Arkansas and Michigan locations in the spring. In addition, a fall chisel plow tillage event occurred for experiments conducted in Michigan. In Arkansas, beds were pulled before planting, whereas trials were flat planted in Michigan. Preplant fertilizer was applied when needed based on soil test results for each location and fertilizer recommendations from the University of Arkansas and Michigan State University (MSU) 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 seven-day period for trials in Arkansas beginning six weeks after emergence. Trials in Michigan were conducted under non-irrigated conditions, a common practice for soybean grown in this region. In Arkansas, herbicide applications were made using a CO_2-pressurized backpack sprayer and a four-nozzle boom calibrated to deliver 140 L ha^{-1} at 4.8 km hr^{-1} using AIXR 110015 nozzles (TeeJet Technologies, Springfield, IL). In Michigan, applications were made using a tractor-mounted sprayer calibrated to deliver 178 L ha^{-1} at 6.1 km hr^{-1} using AIXR 11003 nozzles (TeeJet Technologies, Springfield, IL).

Influence of Application Timing of a Diflufenican-Containing Premixture on Soybean Tolerance and Weed Control

Field experiments were conducted at the Milo J. Shult Agriculture Research and Extension Center in Fayetteville, AR (36.0968 -94.17451), and MSU Horticulture Research and

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Extension Center in Holt, MI (35.67613 -90.0851), in 2022 and 2023 (Table 1). Following ground preparation, soybean cultivar AG45XFO (Bayer CropScience, St. Louis, MO) was planted at 346,000 seeds ha^{-1} into four-row plots (91 cm spacing) measuring 6.1 m in length at Fayetteville, AR. An AG24XF1 and AG26XF3 soybean cultivar was planted at 371,000 seeds ha^{-1} in 2022 and 2023 at Holt, MI, into four-row plots (76 cm spacing) measuring 9.1 m in length.

The experiment was designed as a randomized complete block with four replications and two factors for the tolerance trials (herbicide rate and application timing) and one factor (application timing) for the weed control trial. For the tolerance trials, the DFF-containing premixture was applied at 120:240:330 (1X) and 240:480:660 (2X) g ai ha^{-1}, respectively, in Arkansas. In Michigan, the DFF containing premixture was applied at 150:300:410 (1X) and 300:600:810 g ai ha^{-1} (2X) due to the adjusted rates for the different soil textures (Table 1). For the weed control trials, only a 1X rate of the diflufenican:metribuzin:flufenacet premixture was utilized for each location. Four application timings were evaluated in tolerance and weed control trials, including 14-d preplant (DPP), 7 DPP, PRE, and 3 DAP (Table 2). The tolerance trial was weed-free throughout the growing season using standard postemergence (POST) soybean herbicides.

Influence of Soybean Cultivar Tolerance Response to Diflufenican and Diflufenican:Metribzuin:Flufenacet Premixture

Field experiments were conducted at the Pine Tree Research Station near Colt, AR (35.1248 -90.93134), and the MSU Horticulture Teaching and Research Center in Holt, MI (35.67613 -90.0851) in 2022 and 2023 (Table 3). In Arkansas, three Asgrow soybean cultivars (Table 4) were cone planted at 346,000 seeds ha^{-1} into four-row plots (76 cm spacing) measuring 6.1 m in length. Cultivars for Arkansas were selected based on the University of Arkansas System Division of Agriculture 2021 metribuzin tolerance screening, with two cultivars being “moderately” sensitive to metribuzin and one rated as “highly” sensitive (Ross et al. 2021). In Michigan, three Asgrow cultivars (Table 4) were planted at 371,000 seeds ha^{-1} into four-row plots (76 cm spacing) measuring 9.1 m in length. Of the cultivars utilized, one was moderately sensitive, one highly sensitive, and the other had an unknown sensitivity to metribuzin.

The experiments were designed as a randomized complete block with four replications and three factors (metribuzin sensitivity, herbicide, and rate). At all locations, diflufenican and the DFF-containing premixture were applied PRE. Diflufenican was applied at 120 (1X) and 240 (2X) g ai ha^{-1}, respectively, in Arkansas and 150 (1X) and 300 (2X) g ai ha^{-1}, respectively, in Michigan. In addition, the DFF-containing premixture was applied at 120:240:330 (1X) and 240:480:660 (2X) g ai ha^{-1}, respectively, in Arkansas and 150:300:410 (1X) and 300:600:810 (2X) g ai ha^{-1}, respectively, in Michigan due to the differences in soil texture (Table 3). All trials were managed as weed-free using standard POST soybean herbicides.

Data collection

Visible injury ratings were collected 14, 28, and 42 DAP for the application timing and soybean cultivar tolerance trials. In addition, weed control ratings of annual grasses (broadleaf signalgrass (*Urochloa platyphylla* Wright), goosegrass (*Eleusine indica* L.), and foxtail ssp. (Setaria SSP.)), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), Palmer amaranth, and velvetleaf (*Abutilon theophrasti* L.) (Table 5) were collected 28 and 42 DAP. All ratings were taken on a scale of 0% to 100%, with 0% representing no crop injury or weed control and 100% representing complete crop death or weed control (Frans and Talbert 1977). For the soybean cultivar tolerance trials, stand counts of two 1-m sections of the row were collected at 14 DAP in Arkansas in 2022 and 2023. Ground coverage images were captured using an unmanned aerial system [DJI Mavic Air 2S (DJI Technology CO, LTD., Nanshan, Shenzhen, China)] 14 and 42 DAP for Arkansas application timing tolerance trials. Overhead images were analyzed using Field Analyzer (Green Research Services, LLC., Fayetteville, AR) to determine the percentage of crop groundcover. Palmer amaranth density was collected in two 0.5 m^2 quadrats per plot in Arkansas in the application timing weed control experiments in 2022 and 2023. In addition, Palmer amaranth biomass was collected at harvest from each plot by cutting weeds present at the soil surface and placing them into biomass bags. All harvested plant material was placed into an oven at 66 C for two weeks, and dry biomass was recorded. Lastly, soybean grain yield was collected by harvesting the center two rows of each plot at each location using a small-plot combine and adjusted to 13% moisture.

Data analysis

Statistical analysis was performed using R studio version 4.3.2 (R Core Team 2022) and the 'glmmTMB' function (glmmTMB package; Brooks et al. 2017). For the application timing tolerance experiments, injury, relative groundcover, and relative yield were fit to a generalized linear mixed-effect model by evaluation timing (GLMM). For the injury model 14 DAP, data from Michigan in 2022 and 2023 were excluded due to the lack of injury violating the ANOVA assumptions for variance. (Emerson 2022). Additionally, injury data from Michigan in 2023 was excluded from the model at 28 DAP due to the lack of variance. By 42 DAP, all sites were included in the model because injury was observed at all sites. Site year, herbicide rate, and application timings were considered fixed effects due to the drastic differences in injury among sites, which can be attributed to the total differences in rainfall or irrigation (Table 6). Replication was considered a random effect, and all injury data were bound between 0 and 1 and analyzed using a beta distribution (Gbur et al. 2012). Groundcover and yield were made relative to the nontreated check and analyzed using a Gaussian or normal distribution after the residual failed to violate the Shapiro-Wilks normality test. For the application timing weed control experiment, Palmer amaranth, annual grasses, common lambsquarters, common ragweed, and velvetleaf control, Palmer amaranth density and biomass, and grain yield were fit to a GLMM by evaluation timing. Weed control ratings were excluded for PRE treatments in Michigan in 2022 due to a sprayer malfunction. Application timing was considered a fixed effect, and replication nested within a location was considered random. All control data were analyzed using a beta distribution (Gbur et al. 2012). Palmer amaranth density was analyzed using a Poisson distribution. Palmer amaranth biomass and grain yield were analyzed using a Gaussian or normal distribution. Injury, stand counts, and grain yield were fit to a GLMM by evaluation timing for the soybean cultivar tolerance experiments. Soybean cultivars were grouped based on metribuzin sensitivity (moderate vs. high). The metribuzin sensitivity of the AG24XF1 cultivar was unknown, but the injury was comparable to the AG27XF1 cultivar; therefore, it was included in the "high" metribuzin sensitivity group. Metribuzin sensitivity, herbicide, and herbicide rate were considered fixed effects, and replication nested within location was considered random. All injury data were analyzed using a beta distribution (Gbur et al. 2012). Stand counts and grain yield were made relative to the nontreated check and 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 the Type III Wald chi-square test. Estimated marginal means (Searle et al. 1980) 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

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generated using the multcomp package (Horthorn et al. 2008) to visually represent significantly different groups.

Results and Discussion

Influence of Application Timing of a Diflufenican-Containing Premixture on Soybean Tolerance

Soybean injury ranged from 0% to 60% across the site years, application timings, and rates of the DFF-containing premixture evaluated 14 DAP (Figure 1). Injury observed at 14 DAP included bleaching, necrosis, and reduced crop vigor, with bleaching being the most prominent symptom. The greatest injury occurred in Arkansas in 2023, with no crop response in Michigan in 2022 and 2023 at 14 DAP. Variability in injury across the locations and site years is likely attributed to the drastic differences in rainfall. At the Arkansas site, greater than 11.5 cm of rainfall occurred from two weeks before planting until two weeks after planting; however, only 1.1 cm of rainfall occurred in the same period at the Michigan site in 2023 (Table 6). Previous research has shown that soybean injury from diflufenican alone was greater during years of higher rainfall amounts (Laplante 2022). In addition, injury increased the closer the application of the DFF-containing premixture was made to soybean emergence in Arkansas in 2022 and 2023 (Figure 1). Similarly, in other research, soybean injury from metribuzin, sulfentrazone, and sulfentrazone + cloransulam-methyl was reduced when applying the herbicides PP compared to PRE applications (Moshier and Russ 1981; Priess et al. 2020). Soybean injury from the 2X rate of the DFF-containing premixture was higher than the 1X rate at all application timings, except 7 DPP in 2022 and 2023 and PRE in 2022. Ground coverage by soybean 14 DAP was reduced for the PRE and 3 DAP application timings in Arkansas in 2023 relative to the nontreated check (Table 7). The reduction in ground coverage is attributed to the high degree of visible injury caused by the DFF-containing premixture applied PRE and 3 DAP.

A similar trend occurred at 28 DAP, with soybean injury ranging from 0% to 55% across site years, application timings, and herbicide rate (Figure 2). Unlike the 14 DAP evaluations, soybean injury was observed at 28 DAP in Michigan in 2022, attributed to 4.9 cm of rainfall after the first evaluation (Table 6). Additionally, the trend of greater soybean injury occurring the closer the application of the DFF-containing premixture was made to soybean emergence remained (Figure 2). However, injury from the 2X rate of the DFF-containing premixture was

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only greater than the 1X at one location for applications occurring at 14 DPP, two locations 7 DPP, one location PRE, and one location 3 DAP.

Excluding the 2X rate of the DFF-containing premixture in Arkansas in 2023, soybean injury was less than 20% across site years, application timings, and herbicide rate by 42 DAP (Figure 3). Soybean injury was first observed at this evaluation in Michigan in 2023, likely due to 5.3 cm of rainfall following the 28 DAP evaluation (Table 6). In addition, this indicates that the DFF-containing premixture can persist at a level that causes crop response up to 42 DAP. At Arkansas, the bleaching symptomology observed at previous evaluation timings had subsided by 42 DAP, and the injury observed was in the form of reduced crop vigor or stunting. Applications that occurred PRE and 3 DAP were the most injurious at 42 DAP; however, soybean injury was less than 15% for the 1X rate of the DFF-containing premixture at all locations (Figure 3). In addition, no reductions in ground coverage occurred relative to the nontreated check by 42 DAP in Arkansas in 2022 and 2023 (data not shown).

Soybean grain yield in the nontreated control was 3,700 kg ha^{-1} and 4,900 kg ha^{-1} in Arkansas in 2022 and 2023, and 4,500 kg ha^{-1} and 3,300 kg ha^{-1} in Michigan in 2022 and 2023 (data not shown). Overall, there were no differences in grain yield regardless of application timing or rate of the DFF-containing premixture at each location relative to the nontreated check, indicating that the early season injury and negative effects of the DFF-containing premixture did not translate to yield loss. Soybean was planted during the optimal portion of the growing season in both states. Any delay in planting and subsequent injury would likely reduce its ability to recover before reproductive development and increase the likelihood of yield loss.

Influence of Application Timing of a Diflufenican-Containing Premixture on Weed Control

Soybean injury was less than 5% for all application timings by 28 DAP in the weed control experiments (Table 8). Over 80% control of all weeds was observed for all application timings of the DFF-containing premixture at 28 DAP. Control of annual grasses, velvetleaf, and Palmer amaranth increased the closer the applications of the DFF-containing premixture occurred to soybean emergence. A similar trend occurred for Palmer amaranth density 28 DAP, with PRE and 3 DAP application timings having the lowest density (Table 9); however, all application timings reduced Palmer amaranth emergence >85% relative to the nontreated control.

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Common lambsquarters control was greatest for the 7 DPP and 3 DAP application timings, and no differences occurred in the control of common ragweed across application timings (Table 8).

Previous research found that Palmer amaranth density was lower for herbicides applied PRE compared to PP 28 d after emergence in a year where adequate rainfall occurred (Priess et al. 2020). However, another site year provided an example of timely activation via rainfall that did not occur, causing higher Palmer amaranth density in plots receiving PRE than PP treatments. Herbicides that are applied PP have a greater chance of obtaining adequate rainfall for herbicide activation; however, cumulative rainfall amounts dictate the length of persistence (Oliver et al. 1993). Soybean in Arkansas is grown under irrigated conditions, allowing for activation of PRE herbicides if sufficient rainfall does not occur; however, soybean grown in Michigan are under non-irrigated conditions and require adequate rainfall to activate PRE herbicides. Therefore, if the DFF-containing premixture was applied PRE and adequate rainfall did not occur, producers would have to rely upon POST herbicides to control weeds, increasing the chance of weeds evolving resistance to POST herbicides (Norsworthy et al. 2012).

By 42 DAP, the trend remained for applications of the DFF-containing premixture being more effective closer to soybean emergence, where greater control of velvetleaf, Palmer amaranth, and annual grasses occurred (Table 10). However, common lambsquarters control was greatest for the 7 DPP application timing of the DFF-containing premixture. While the DFF-containing premixture did provide >70% control of all weeds evaluated, producers cannot rely on the DFF-containing premixture alone for season-long weed control. Therefore, producers should make POST applications after applying the DFF-containing premixture PRE in combination with soil residuals to achieve season-long weed control (Meyer et al. 2015; Norsworthy et al. 2012).

All application timings of the DFF-containing premixture reduced Palmer amaranth biomass relative to the nontreated check by soybean harvest (Table 9). However, greater reductions occurred the closer the herbicide application occurred to soybean emergence. In addition, soybean grain yield was reduced with a 14 DPP application of the DFF-containing premixture compared to 3 DAP, indicating inferior season-long weed control with the earlier application timing.

Influence of Soybean Cultivar Tolerance in Response to Diflufenican and Diflufenican:Metribzuin:Flufenacet Premixture

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Soybean sensitivity to metribuzin as a main effect or all possible interactions involving the factor was insignificant at 14 and 28 DAP (data not shown). Across locations, soybean injury was <15% for diflufenican and the DFF-containing premixture at a 1X and 2X rate of each herbicide 14 DAP. However, injury was greater with a 2X rate of both herbicides relative to the 1X rate, and greater injury occurred following the 2X rate of the DFF-containing premixture than the 2X rate of diflufenican alone. The soybean density in the nontreated control averaged 19 plants m^{-1} of row (248,000 plants ha^{-1}) for the “moderate” and “high” metribuzin sensitivity groups in Arkansas (data not shown). Overall, no reductions in soybean density occurred regardless of metribuzin sensitivity, herbicide, or herbicide rate 14 DAP.

Previous research has shown that soil pH is a key component of metribuzin injury in soybean. Metribuzin at a rate of 0.6 and 0.8 kg ai ha^{-1} on a silty clay loam at pH 6.6 caused 15% to 26% injury; however, the same rates of metribuzin on a silt loam at pH 7.9 resulted in >60% soybean injury (Moomaw and Martin 1978). Soil pH at all research locations ranged from 6.3 to 7.6 (Table 3); however, the lack of greater soybean injury to “high” metribuzin-sensitive cultivars is likely attributed to the low metribuzin rate in the DFF-containing premixture. The metribuzin rate in the DFF-containing premixture is 240 g ai ha^{-1} for the anticipated 1X rate on a silt loam, which is less than the lowest recommended rate for metribuzin alone (420 g ai ha^{-1}) (Barber et al. 2024). However, it is not uncommon for premixtures containing metribuzin to have reduced herbicide rates. For example, Boundary®, a widely used PRE option in soybean, containing *S*-metolachlor and metribuzin, has a recommended rate of only 260 g ai ha^{-1} of the latter herbicide on a silt loam (Anonymous 2023; Schwart-Lazaro et al. 2018).

By 28 DAP, soybean injury averaged over metribuzin sensitivity was <20% regardless of herbicide and herbicide rate. The trend of higher injury with a 2X rate with both diflufenican and the DFF-containing premixture compared to 1X rates was observed (Table 11). In addition, greater injury caused by the 2X rate of the DFF-containing premixture than the 2X rate of diflufenican alone remained. By 42 DAP, soybean injury was ≤5%, with no differences in herbicide or herbicide rate (data not shown).

Soybean grain yield in the nontreated control was 3,430 kg ha^{-1} for the “moderate” metribuzin-sensitive group and 3,700 kg ha^{-1} for the “high” metribuzin-sensitive group across locations, respectively (data not shown). Overall, no differences in grain yields occurred regarding metribuzin sensitivity, herbicide, or herbicide rates relative to the nontreated control.

Practical Implications

Based on the research conducted here, the DFF-containing premixture has a flexible application timing that should be 7 DPP until PRE to reduce soybean injury. A crop response should be anticipated if producers plan to plant early and more than 2.5 cm of rain is forecasted. The soybean injury observed was trainset and did not translate to grain yield reductions. Regarding weed control, producers should not apply the DFF-containing premixture earlier than 7 DPP, or else a reduction in efficacy is likely. Under growing conditions in Arkansas, producers can delay the application closer to planting due to the ability to activate the herbicide with irrigation that exists in most fields; however, non-irrigated systems typical to Michigan should utilize the herbicide preplant or plant when adequate rainfall is forecasted. The DFF-containing premixture applied PRE or 3 DAP provided ≥90% control of problematic weeds such as Palmer amaranth at 42 DAP, offering producers with Group 14 or 15 resistance an effective alternative PRE option. However, the DFF-containing premixture alone will not achieve season-long weed control and should be utilized as part of a season-long herbicide program. Although the DFF-containing premixture does contain metribuzin, the herbicide will likely be able to be used across all soybean cultivars as soybean injury was comparable regardless of metribuzin sensitivity due to the low rate of metribuzin in the premixture. Overall, the DFF-containing premixture provides a new tool that soybean producers can integrate into a season-long herbicide program to control problematic weeds.

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Competing Interests

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Table 1. Soil series, texture, organic matter, and pH for Fayetteville, AR, and Holt, MI in 2022 and 2023 for application timing tolerance and weed control experiments.[a]

	Location			
	Fayetteville, AR[b]		Holt, MI	
	2022	2023	2022	2023
Soil series[c]	Leaf		Conover	Capac
Soil texture	-------Silt loam------		Loam	Sandy clay loam
Sand (%)	13		45	52
Silt (%)	75		30	28
Clay (%)	12		25	20
OM (%)	1.8		2.8	3.1
pH	6.5		6.5	6.3

[a]Abbreviations: OM, organic matter

[b]Trial was conducted in an adjacent location within the field in 2022 and 2023

[c]Soil series and texture were obtained from USDA-NRCS 2024

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Table 2. Dates for herbicide applications and planting for application timing tolerance and weed control experiments conducted in Fayetteville, AR, and Holt, MI, in 2022 and 2023.[a]

Tolerance						
Location	Year	14 DPP	7 DPP	PRE	Planting	3 DAP
Fayetteville, AR	2022	May 19	May 27	June 3	June 3	June 6
	2023	April 18	April 24	May 2	May 2	May 5
Holt, MI	2022	May 10	May 17	May 23	May 23	May 26
	2023	May 8	May 16	May 23	May 23	May 26

Weed control						
Location	Year	14 DPP	7 DPP	PRE	Planting	3 DAP
Fayetteville, AR	2022	May 19	May 27	June 3	June 3	June 6
	2023	May 18	May 25	June 2	June 2	June 5
Holt, MI	2022	May 10	May 17	May 23	May 23	May 26
	2023	May 8	May 16	May 23	May 23	May 26

[a]Abbreviations: 14 DPP, 14-d preplant; 7 DPP, 7-d preplant; PRE, preemergence; 3 DAP, 3 d after planting

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Table 3. Soil series, texture, organic matter, and pH for near Colt, AR, and Holt, MI in 2022 and 2023 for soybean variety tolerance experiments.[a]

	Location			
	Colt, AR		Holt, MI	
	2022	2023	2022	2023
Soil series[b]	Calhoun	Calloway	Conover	Capac
Soil texture	Silt loam	Silt loam	Loam	Sandy clay loam
Sand (%)	12	12	43	52
Silt (%)	70	70	34	28
Clay (%)	18	18	23	20
OM (%)	1.2	1.3	2.3	3.1
pH	7.6	6.6	6.9	6.3

[a]Abbreviations: OM, organic matter

[b]Soil series and texture were obtained from USDA-NRCS 2024

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Table 4. Cultivar, location, manufacturer, and metribuzin sensitivity for cultivars utilized in soybean variety experiments.

Cultivar	Location	Manufacturer	Metribuzin sensitivity	Maturity Group
AG45XF0	AR	Bayer CropScience St. Louis, MO	Moderate	4.5
AG48XF0	AR	Bayer CropScience St. Louis, MO	Moderate	4.8
AG53XF2	AR	Bayer CropScience St. Louis, MO	High	5.3
AG21XF1	MI	Bayer CropScience St. Louis, MO	Moderate	2.1
AG24XF1[a]	MI	Bayer CropScience St. Louis, MO	Unknown	2.4
AG27XF1	MI	Bayer CropScience St. Louis, MO	High	2.7

[a]The metribuzin sensitivity was unknown for AG24XF1; however, the cultivar behaved similarly to AG27XF1 in regard to injury therefore, it was included in the high metribuzin sensitivity group

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Table 5. Weed species present each year across locations for the diflufenican:metribuzin:flufenacet premixture application timing weed control experiment.

Location	Year	Weed species
Fayetteville, AR	2022	common lambsquarters
		goosegrass
		Palmer amaranth
Fayetteville, AR	2023	broadleaf signalgrass
		Palmer amaranth
Holt, MI	2022	common lambsquarters
		common ragweed
		foxtail ssp.
		velvetleaf
Holt, MI	2023	common lambsquarters
		common ragweed
		foxtail ssp.
		velvetleaf

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Table 6. Rainfall or irrigation totals ranging from 14-d preplant until 42 d after planting for the diflufenican:metribuzin:flufenacet premixture application timing tolerance experiment at Fayetteville, AR, and Holt, MI in 2022 and 2023.

	Location			
	Fayetteville, AR		Holt, MI	
Interval (weeks)	2022	2023	2022	2023
	--------------------------------cm--------------------------------			
-2 to -1	6.22	0.46	0.81	0.12
-1 to 0	0.10	3.78	1.70	1.04
0 to 1	4.24	2.75	1.02	0.00
1 to 2	1.27	4.11	0.13	0.00
2 to 3	1.27	1.29	4.85	0.25
3 to 4	1.27	1.27	0.10	0.00
4 to 5	1.27	5.36	0.13	1.37
5 to 6	1.27	3.46	0.91	4.01
Total	16.91	22.48	9.65	6.79

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Table 7. Influence of application timing of the diflufenican:metribuzin:flufenacet premixture averaged over rate on ground coverage for Fayetteville, AR in 2022 and 2023 at 14 DAP.[a]

Year	Timing[b]	Mean[c]	Lower CI	Upper CI
		--------------------%--------------------		
2022	14 DPP	115	95	135
	7 DPP	85	65	105
	PRE	102	82	122
	3 DAP	85	65	106
2023	14 DPP	114	93	134
	7 DPP	100	80	121
	PRE	71*	51	91
	3 DAP	58*	37	78

[a]Abbreviations: DAP, d after planting; 14 DPP, 14-d after planting; 7 DPP, 7-d after planting; PRE, preemergence; 3 DAP, 3 d after planting; Lower CI, lower confidence interval; Upper CI, upper confidence interval

[b]The timing by location interaction was significant (<0.001), therefore rates of the diflufenican:metribuzin:flufenacet premixture were averaged over application timing.

[c]Values that do not contain a * are not statically different from the nontreated check

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Table 8. Influence of different application timings of a diflufenican:metribuzin:flufenacet premixture on soybean injury and Palmer amaranth, common ragweed, velvetleaf, common lambsquarters, and annual grass control averaged over location 28 DAP.[a]

			Control[b,c]									
Timing	INJ		AMAPA		AMBEL		ABUTH		CHEAL		ANGR[d]	
	--%--------------------------------------											
14-d preplant	0	b	84	b	90		85	b	90	b	81	b
7-d preplant	0	b	91	b	95		95	a	97	a	94	a
PRE[e]	3	a	97	a	---		---		89	b	92	a
3 d after planting	3	a	98	a	96		96	a	96	ab	94	a
P-value	<0.0001		<0.0001		0.166		0.0066		0.0139		0.0002	

[a]Abbreviations: DAP, d after planting; PRE, preemergence; INJ, injury; AMAPA, Palmer amaranth; AMBEL, common ragweed; ABUTH, velvetleaf; CHEAL, common lambsquarters; ANGR, annual grasses

[b]Means within a column followed by the same letter are not different according to Sidak Method (α=0.05)

[c]Site years for evaluations: INJ, (four); AMAPA, (two); AMBEL, (two); ABUTH, (two); CHEAL, (three); ANGR, (four)

[d]Annual grasses included foxtails, goosegrass, and broadleaf signalgrass

[e]Preemergence treatment was omitted due to sprayer issues in Holt, MI, in 2022

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Table 9. Influence of different application timings of a diflufenican:metribuzin:flufenacet premixture on Palmer amaranth density 28 DAP, Palmer amaranth biomass at Fayetteville, AR, and grain yield.

Timing	Density[b,c] AMAPA			Biomass AMAPA		Grain yield	
	# m^{-2}			g m^{-2}		kg ha^{-1}	
Nontreated	-			145	a	1,900	c
14-d preplant	1.0	a	(87.1)[d]	89	b	2,900	b
7-d preplant	0.8	a	(89.4)	58	bc	3,250	ab
PRE[e]	0.1	b	(98.2)	26	c	3,280	ab
3 d after planting	0.1	b	(98.9)	16	c	3,470	a
P-value	<0.0001			<0.0001		<0.0001	

[a]Abbreviations: DAP, d after planting; PRE, preemergence; AMAPA, Palmer amaranth

[b]Means within a column followed by the same letter are not different according to Sidak Method (α=0.05)

[c]Site years for evaluations: Density, (two); Biomass, (two); Grain yield, (four)

[d]Numbers in parenthesis represent Palmer amaranth density reduction relative to the nontreated check

[e]Preemergence treatment was omitted for yield at Holt, MI, in 2022 due to sprayer issues

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Table 10. Influence of different application timings of a diflufenican:metribuzin:flufenacet premixture on soybean injury and Palmer amaranth, common ragweed, velvetleaf, common lambsquarters, and annual grass control averaged over location 42 DAP.[a]

Timing	INJ	Control[b,c]									
		AMAPA		AMBEL		ABUTH		CHEAL		ANGR[d]	
	---%------------------------------------										
14-d preplant	1	71	b	87		85	b	87	b	79	b
7-d preplant	1	80	b	95		94	a	97	a	91	a
PRE[e]	1	91	a	----		---		88	b	89	a
3 d after planting	2	93	a	93		96	a	92	b	91	a
P-value	0.3555	<0.0001		0.1364		0.0051		<0.0001		<0.0001	

[a]Abbreviations: DAP, d after planting; PRE, preemergence; INJ, injury; AMAPA, Palmer amaranth; AMBEL, common ragweed; ABUTH, velvetleaf; CHEAL, common lambsquarters; ANGR, annual grasses

[b]Means within a column followed by the same letter are not different according to Sidak Method (α=0.05)

[c]Site years for evaluations: INJ, (four); AMAPA, (two); AMBEL, (two); ABUTH, (two); CHEAL, (three); ANGR, (four)

[d]Annual grasses included foxtails, goosegrass, and broadleaf signalgrass

[e]Preemergence treatment was omitted due to spray issues in Holt, MI, in 2022

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Table 11. Influence of various rates of diflufenican and diflufenican:metribuzin:flufenacet premixture averaged over metribuzin sensitivity and location for soybean injury 14 and 28 DAP.[a]

Herbicide	Rate	Injury[b] 14 DAP		28 DAP	
		------------%------------			
Diflufenican	1X	3	c	4	c
Diflufenican	2X	8	b	15	b
Diflufenican:metribuzin:flufenacet	1X	4	c	4	c
Diflufenican:metribuzin:flufenacet	2X	13	a	18	a
P-value		0.0329		0.0421	

[a]Abbreviations: DAP, d after planting

[b]Means within a column followed by the same letter are not different according to Sidak Method (α=0.05)

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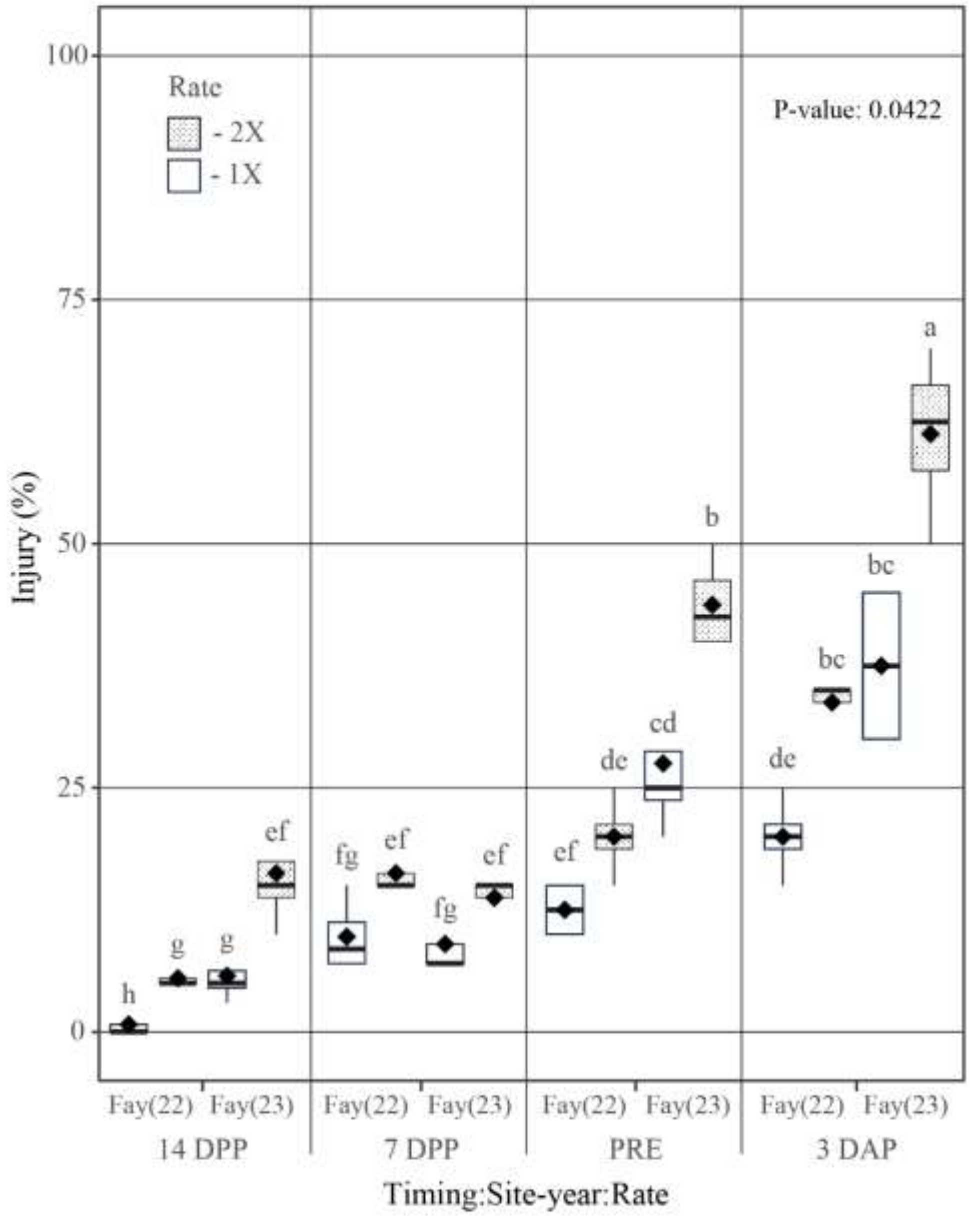

Figure 1. Box and whisker plots depict injury from the diflufenican:metribuzin:flufenacet premixture across application timings, locations, and rates 14 d after planting. Bars containing the same letter are not statically different according to Sidak Method (α=0.05). Injury evaluations were collected at Fayetteville, AR, in 2022 and 2023 and Holt, MI, in 2022 and 2023; however, no injury occurred at MI in 2022 and 2023. Abbreviations: 14 DPP, 14-d preplant; 7 DPP, 7-d preplant; PRE, preemergence; 3 DAP, 3 d after planting; Fay(22), Fayetteville 2022; Fay(23) Fayetteville 2023; MI(22), Michigan 2023.

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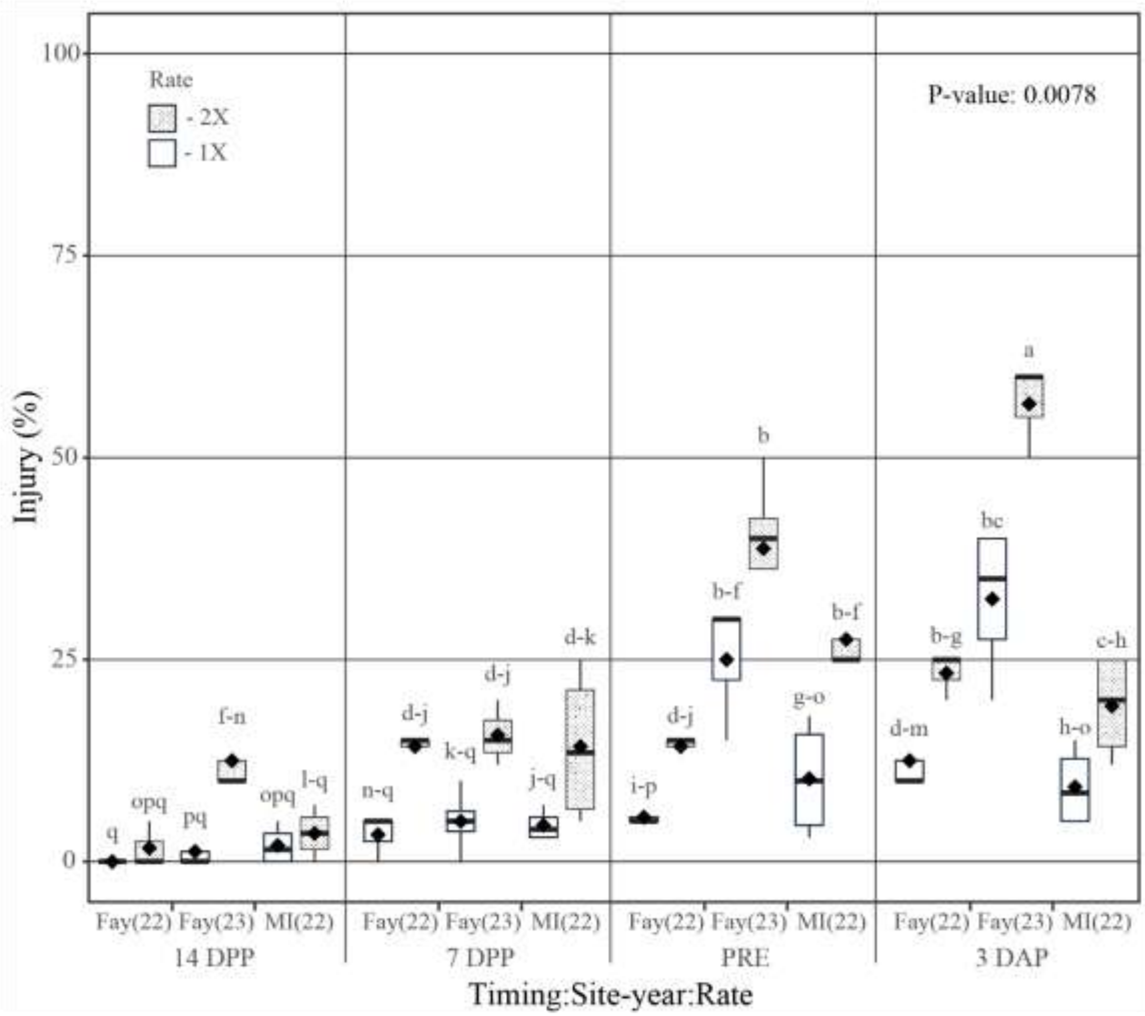

Figure 2. Box and whisker plots depict injury from the diflufenican:metribuzin:flufenacet premixture across application timing, site years, and rates 28 d after planting. Bars containing the same letter are not statically different according to Sidak Method (α=0.05). Injury evaluations were collected at Fayetteville, AR, in 2022 and 2023, and Holt, MI, in 2022 and 2023; however, no injury occurred in MI in 2023. Abbreviations: 14 DPP, 14-d preplant; 7 DPP, 7-d preplant; PRE, preemergence; 3 DAP, 3 d after planting; Fay(22), Fayetteville 2022; Fay(23) Fayetteville 2023; MI(22), Michigan 2023.

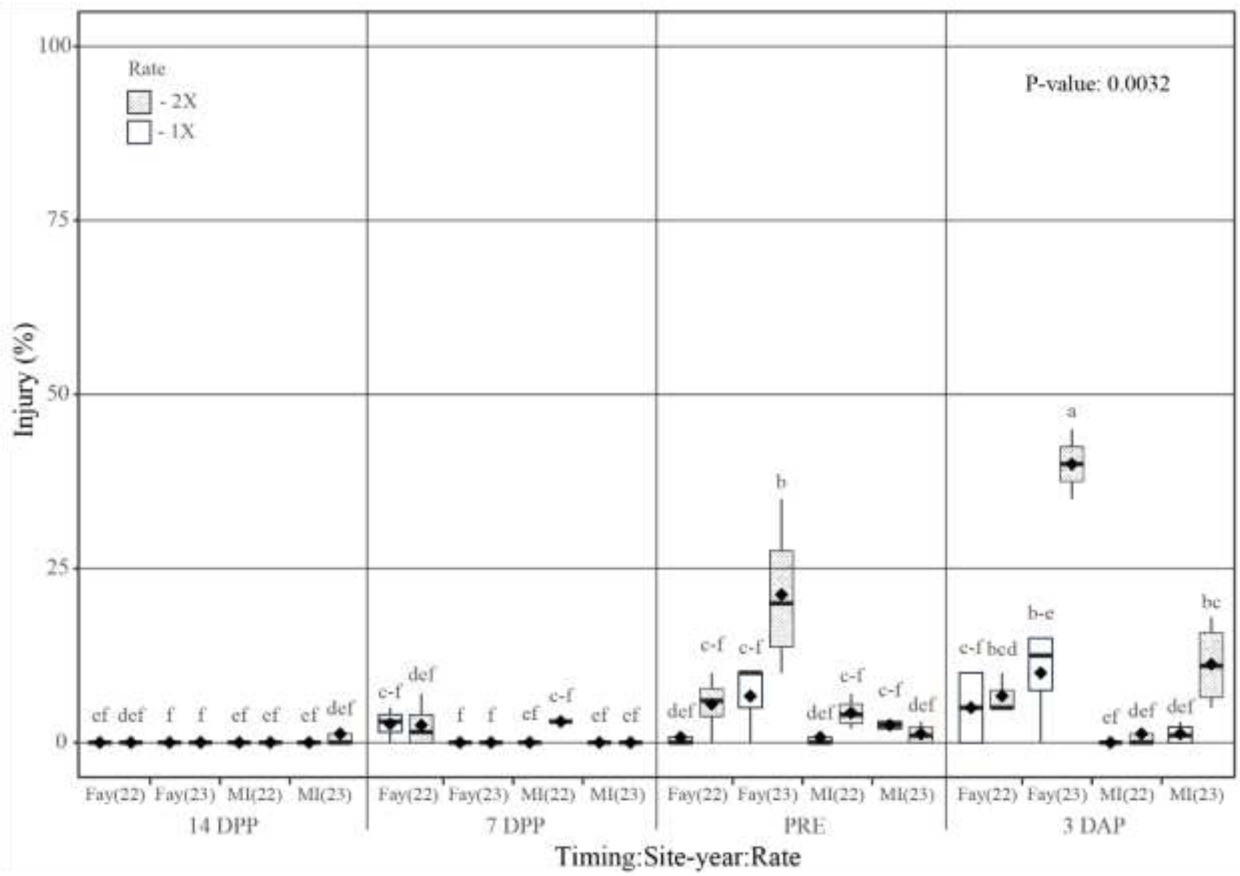

Figure 3. Box and whisker plots depict injury from the diflufenican:metribuzin:flufenacet premixture across application timing, site years, and rates 42 d after planting. Bars containing the same letter are not statically different according to Sidak Method (α=0.05). Injury evaluations were collected at Fayetteville, AR, in 2022 and 2023, and Holt, MI, in 2022 and 2023. Abbreviations: 14 DPP, 14-d preplant; 7 DPP, 7-d preplant; PRE, preemergence; 3 DAP, 3 d after planting; Fay(22), Fayetteville 2022; Fay(23) Fayetteville 2023; MI(22), Michigan 2023.