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Response of corn to reduced rates of tiafenacil applied at vegetative growth stages

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Abstract

Tiafenacil is a new nonselective protoporphyrinogen IX oxidase (PPO)–inhibiting herbicide with both grass and broadleaf activity labeled for preplant application to corn, cotton, soybean, and wheat. Early-season corn emergence and growth often coincides in the mid-South with preplant herbicide application in cotton and soybean, thereby increasing opportunity for off-target herbicide movement from adjacent fields. Field studies were conducted in 2022 to identify the impacts of reduced rates of tiafenacil (12.5% to 0.4% of the lowest labeled application rate of 24.64 g ai ha^{-1}) applied to two- or four-leaf corn. Corn injury 1 wk after treatment (WAT) for the two- and four-leaf growth stages ranged from 31% to 6% and 37% to 9%, respectively, whereas at 2 WAT these respective ranges were 21.7% to 4% and 22.5% to 7.2%. By 4 WAT, visible injury following the two- and four-leaf exposure timing was no greater than 8% in all instances except the highest tiafenacil rate applied at the four-leaf growth stage (13%). Tiafenacil had no negative season-long impact, as the early-season injury observed was not manifested in a reduction in corn height 2 WAT or yield. Application of tiafenacil directly adjacent to corn in early vegetative stages of growth should be avoided. In cases where off-target movement does occur, however, affected corn should be expected to fully recover with no impact on growth and yield, assuming adequate growing conditions and agronomic/pest management practices are provided.

Introduction

Realized benefits of conservation tillage systems can include improved soil health, decreased erosion, maximized water infiltration, improvement in nutrient cycling, and a build-up in organic matter (Creech 2022; Farmaha et al. 2021; Lal 2015). Utilization of conservation tillage in crop production can lead to a potential 2,888-million-liter reduction in diesel equivalents per year as well as 7.7 billion kg yearly reduction in associated emissions of carbon dioxide equivalents (Creech 2022). By 2022, approximately 87% of all cropland acres in the United States were reported to be implementing some form of a conservation tillage production system, defined as tillage being reduced for at least one crop in a given field (Creech 2022). Of this conservation tillage system acreage, continuous no-till accounted for one-third.

Conservation tillage systems rely greatly on herbicides for effective preplant weed management. Numerous herbicides or combinations of herbicides are currently labeled and recommended for preplant or "burndown'" control of many common and troublesome weed species encountered in corn, cotton, and soybean production fields (Anonymous 2024a, 2024b, 2024c; Anonymous 2023a). Herbicide resistance issues and difficult-to-control species have necessitated the identification of novel strategies, such as cover crops and herbicides, for continued successful preplant weed management in production systems (Flessner and Pittman 2019; Johanning et al. 2016; Vollmer et al. 2019; Westerveld et al. 2021a, 2021b; Zimmer et al. 2018).

Tiafenacil, a new protoporphyrinogen IX oxidase (PPO)–inhibiting herbicide developed by FarmHannong Co., Ltd., Korea, exhibits effective nonselective contact activity on both weed and crop species (Anonymous 2023b; Park et al. 2018). PPO-inhibiting herbicides halt the production of protoporphyrin IX (PPIX) from protoporphyrinogen IX (PPGIX), eventually preventing chlorophyll and heme biosynthesis. The increase in PPIX in the cytoplasm results in increases in singlet oxygen, which leads to lipid peroxidation, cell membrane destruction, and, ultimately, plant death (Shaner 2014). Tiafenacil is registered in the United States for preplant application to corn, cotton, soybean, and wheat and for defoliation of cotton (Adams et al. 2022; Anonymous 2023b). Limited published research with tiafenacil has focused on weed management. Tiafenacil at 74 g ai ha^{-1} applied with varying urea ammonium nitrate carrier volumes provided 85%, 81%, 92%, and 90% control of barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.), common lambsquarters (*Chenopodium album* L.), kochia (*Bassia scoparia* [L.] A.J. Scott), and redroot pigweed (*Amaranthus retroflexus* L.), respectively, 1 wk after application (Mookodi et al. 2023). Tiafenacil applied at 50 g ai ha^{-1} resulted in 82% control of glyphosate-resistant downy brome (*Bromus tectorum* L.) (Geddes and Pittman 2023) 7 d after treatment (DAT), whereas the same rate co-applied with metribuzin at 400 g ai ha^{-1} resulted in 88% control of glyphosate-resistant horseweed (*Erigeron canadensis* L.) (Westerveld et al. 2021b).

Corn was planted on over 38 million hectares in the United States in 2023 (USDA 2023). Corn emergence and early-season growth often coincides with preplant herbicide applications made in preparation for later planting of soybean or cotton and often occurs in adjacent fields, thereby increasing opportunity for off-target herbicide movement. Drift or off-target movement was previously identified by survey respondents from two separate states as the biggest herbicide application challenge they face (Butts et al. 2021; Virk and Prostko 2022). Additionally, severe crop injury from off-target herbicide movement is possible upwards of 60 m downwind from both ground and aerial applications, which can negatively impact yield, environmental stewardship, and other beneficial species (Butts et al. 2022). As a result, it is imperative to understand the implications on crop growth and development if the crop were to be exposed to an herbicide drift event.

Serious deleterious effects of simulated off-target movement of selective and nonselective herbicides to corn at various growth stages have been demonstrated (Bond et al., 2006; Ellis et al., 2003). Corn growth stage at time of herbicide exposure has also been shown to result in differential sensitivity to herbicides labeled for corn application. Johnson et al. (2002) reported that mesotrione caused 4% and 11% more corn injury when applied at V5 compared with V3 or V4 growth stages, respectively. Sperry et al. (2019) investigated impacts of foliar application of sublethal rates (12.5% of labeled rate) of paraquat, a nonselective contact herbicide similar to tiafenacil, and fomesafen, a PPO herbicide like tiafenacil, to corn at the V1 through V9 vegetative growth stage. Fomesafen injury 3 DAT ranged from 0 to 38% and declined over time. Compared with the nontreated control (NTC), corn height was reduced approximately 15% 14 DAT with fomesafen applied at V5 or V7. Application at V1 or V7 resulted in a 1,220 and 1,110 kg ha^{-1} yield loss, respectively, compared with the NTC. Yield loss was not observed at any other growth stage. Paraquat injury ranged from 26% to 65%, depending on growth stage and evaluation interval (Sperry et al. 2019). Corn exposed to paraquat at V3 or V5 consistently exhibited greater injury across evaluation intervals compared with other growth stages. Postemergence timings of paraquat resulted in height reduction of 13% to 50%, except at V7. Corn yield loss occurred with all application timings with paraquat compared with the NTC, being reduced 1,740 to 5,120 kg ha^{-1} and generally worsening as exposure time was delayed.

To our knowledge, there exists no published information on the impact of tiafenacil on corn growth and yield following foliar application at sublethal rates that may be encountered in off-target movement events. Therefore, the objective of this research was to determine any negative impacts of foliar application of reduced rates of tiafenacil to corn as affected by growth stage at time of application.

Materials and Methods

Field experiments were conducted in 2022 at the LSU AgCenter Northeast Research Station near St. Joseph, LA (31.9184° N, 91.2335° W), the LSU AgCenter Dean Lee Research and Extension Center near Alexandria, LA (31.17896° N, 92.41052° W), the University of Arkansas System Division of Agriculture Lon Mann Cotton Research Station in Marianna, AR (34.73388° N, 90.76646° W), and the University of Tennessee AgResearch and Education Center in Milan, TN (35.73388° N, 88.72796° W) to determine the impact of reduced rates of tiafenacil (Reviton®, HELM Agro US, Inc., Tampa, FL) applied at differing growth vegetative stages on corn growth and yield. Experiments were conducted in a randomized complete block design, with treatments replicated three or four times. Treatments were applied via compressed air or CO_2 backpack sprayer at 140 L ha^{-1}. Treatments included a factorial arrangement of reduced rates of tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× rate applied to two- or four-leaf corn. The 1× rate basis for reduced-rate calculation was 24.64 g ai ha^{-1}. The tiafenacil label (Anonymous 2023b) allows single application rates from 24.64 to 75.04 g ai ha^{-1}; however, previous unpublished research has indicated that the lower rate in combination with glyphosate provides cost-effective control of most common winter weed species prior to planting (Donnie K. Miller, personal observation). Methylated seed oil was added at 1% v/v to all treatments per label recommendations to maximize weed control (Anonymous 2023b). A comparison 1% methylated seed oil alone treatment was included but resulted in no impacts on parameters measured in comparison to the 0× rate and, therefore, was excluded from statistical analysis. Tiafenacil at designated rates was applied to two- or four- leaf corn hybrid 'DKC 65-99' on April 9 or 27 near St. Joseph, hybrid 'P2089YHR' on April 21 or May 5 near Alexandria, hybrid 'P1222YHR' on May 24 or June 1 in Marianna, and hybrid 'DKC 67-42' on May 19 or 31 in Milan. These timings were selected as being the most likely to exist when burndown of cotton and soybean ground normally occur in the mid-South (authors' personal observations). Plots were maintained weed-free at the St. Joseph and Alexandria locations with as-needed application of glyphosate (Roundup Powermax 3; Bayer CropScience, St Louis, MO) at 1,120 g ai ha^{-1}. Plots at Marianna were kept weed free with a premix of *S*-metolachlor (1,500 g ai ha^{-1}) + mesotrione (166 g ai ha^{-1}) + bicyclopyrone (41 g ai ha^{-1}) + atrazine (699 g ai ha^{-1}) (Acuron; Syngenta, Greensboro, NC) and glyphosate (Roundup Powermax 3; Bayer CropScience, St Louis, MO) at 1,120 g ai ha^{-1} at planting. Plots at Milan were kept weed free by hand-weeding. Parameter measurements included visible injury on a scale of 0 = no injury and 100 = plant death 1, 2, and 4 wk after treatment (WAT); plant height at 2 WAT; and yield.

Statistical Analysis

The four-parameter log-logistic model was fit to corn injury data 1 and 2 WAT.

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Table 1. Nonlinear regression parameters for corn visible injury 1 and 2 wk after treatment (WAT) following application of tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.64 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.[a]

Evaluation	Corn growth stage	*c*	*d*	*b*	*e*	RMSE
1 WAT	Two-leaf	0.025	40.480	−1.073	0.511	11.23
	Four-leaf	0.281	55.849	−0.667	1.208	8.88
2 WAT	Two-leaf	−0.053	33.285	−0.705	1.271	7.50
	Four-leaf	−0.100	28.668	−0.676	0.472	12.53

[a]Parameters: *b* is the slope at the inflection point, *c* is the lower limit, *d* is the upper limit, and *e* is the dose of herbicide corresponding to the midpoint of plant injury response observed between the upper and lower limits. RMSE is root mean square error.

$$Y = c + \frac{d - c}{1 + \exp[b(\ln(x) - \ln(e))]} \quad [1]$$

where Y is injury (%), b is the slope at the inflection point, c is the lower limit, d is the upper limit, e is the dose of herbicide corresponding to the midpoint of plant injury response observed between the upper and lower limits, and x is tiafenacil rate (g ai ha^{-1}) (Table 1). The goodness of fit of the four-parameter log-logistic model was evaluated using the root mean square error (RMSE) (Table 1).

$$RMSE = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N}\left(Y_i - \hat{Y}_i\right)^2} \quad [2]$$

where Y_i is the evaluated injury (%) and $\hat{Y}_i$ is the corresponding value predicted by the model. N is the total number of observations. Smaller RMSE values indicate a better model fit to the data, with values of 0 representing a perfect fit. The Nonlinear Least Squares (nls) of the "stats" was used to fit the four-parameter log-logistic model in R version 4.3.3 (R Core Team, 2024). Data were analyzed by location and model parameters compared (Ritz et al. 2015) with no statistical differences detected between parameters of locations for herbicide rates applied (data not shown). Therefore, data were pooled across locations for curve fitting for a given application stage. In contrast, due to differences observed during application at two-leaf and four-leaf stages, data were analyzed separately for these stages. Model assumptions of homoscedasticity, independence, and normality were checked in each case. A linear regression model was fit to corn injury 4 WAT, corn plant height, and corn yield averaged across locations (Table 2). The linear model (Equation 3) was fit to the data.

$$y = \beta_0 + \beta_1 x + \varepsilon \quad [3]$$

where y represents the response variable of interest (visible injury, plant height; or yield), x represents the rate of tiafenacil (g ai ha^{-1}), β_1 is the slope, the amount by which the response variable changes when the tiafenacil rate increases by one unit, β_0 is the intercept, the value of the response variable when the tiafenacil rate = 0, and ϵ is the residual. The lm() function of the "stats" package was used to fit models in R version 4.3.3 (R Core Team 2024). Data were analyzed by location and model parameters (slopes and intercepts) compared (Ritz et al. 2015), with no statistical differences detected between parameters of locations for herbicide rates applied at the same leaf stage (data not shown). Therefore, data were pooled across locations for line fitting for a given application stage. In contrast, because of differences observed during application at two-leaf and four-leaf stages, data were analyzed separately for these stages. Model assumptions of linearity, homoscedasticity, independence, and normality were checked in each case.

Results and Discussion

Corn Injury

Corn injury was characterized by necrotic speckling of leaves contacted at time of application. The tiafenacil dose resulting in midpoint plant visible injury response observed between the upper and lower limits was 0.511 and 1.208 g ai ha^{-1} for the two- and four-leaf application timings 1 WAT, respectively (Table 1). This corresponded to a predicted visible injury of 20% and 28%, respectively. When applied at the two-leaf growth stage, corn was injured 35% at the highest tiafenacil rate applied (1/8×), with each successive rate reduction resulting in 31%, 25%, 18%, 11%, and 6% visible injury 1 WAT (Figure 1). Similarly, exposure at the four-leaf growth stage resulted in 37%, 28%, 24%, 18%, 13% and 9% visible injury at these same rates (Figure 1). By 2 WAT, midpoint plant visible injury response was at 1.271 and 0.472 g ai ha^{-1} tiafenacil for the two- and four-leaf application timings, respectively, 2 WAT (Table 1). Predicted visible injury of 16.5% and 14.2% was calculated at these respective rates. When applied at the two-leaf growth stage, corn visible injury was 21.7% at the highest tiafenacil rate applied (1/8×), with each successive rate reduction resulting in 17.7%, 13.7%, 10%, 6.9%, and 4.6% (Figure 2). Application at the four-leaf growth stage resulted in similar visible injury to that observed for the two-leaf timing, ranging from 22.4% at the highest tiafenacil rate down to 7.2% for the lowest rate applied (Figure 2). By 4 WAT, visible injury following tiafenacil exposure at the two-leaf corn growth stage resulted in no greater than 8% at any rate (Figure 3). At the later application timing, the highest rate resulted in 13.2% visible injury, whereas all other rates injured corn no greater than 8% (Figure 3). Sperry et al. 2019 reported injury of 18% and 23% 1 WAT with the PPO-inhibiting herbicide fomesafen applied at 12.5% of the labeled rate to V1 and V3 corn and 16% and 22% injury by 2 WAT. By 4 WAT, injury was no greater than 6% with fomesafen, whereas V1 and V3 corn treated with the nonselective contact herbicide paraquat at 12.5% of the labeled rate was still exhibiting 26% and 37% injury at these stages. It was reported in this research that fomesafen exposure resulted in greater injury at all rating intervals at the V5 or V7 growth stages, and this was attributed to possible injury to the plant growing point at or slightly above the soil line at these later timings. In the current research, visible injury levels following exposure to tiafenacil at each rate were similar at the two- or four-leaf growth stages.

Corn Height

Statistical analysis with respect to corn height 2 WAT indicated no negative impact of tiafenacil applied at either timing (Table 2). At 2 WAT, corn height in the absence of tiafenacil averaged 53.3 and 116 cm at the two- and four-leaf growth stage, respectively (Figure 4). Height following tiafenacil exposure ranged from 47 to 53 cm and 105.5 to 113 cm at these respective growth stages. Results were similar to Sperry et al. (2019), who reported that the PPO herbicide fomesafen did not reduce corn height 2 WAT when applied at the V1 or V3 growth stage. Height reduction of 15% and 14% was observed in this research for the V5 and V7 exposure timings, respectively. Conversely, paraquat reduced corn height 36% and 50% when applied at the V1 and V3 growth stages.

Table 2. Linear regression parameters for corn injury 4 wk after treatment (WAT), height 2 WAT, and yield following application of tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.64 g ai ha^{-1} use rate applied to two- or four- leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

Parameter	Evaluation	Timing	Adjusted R^2		Estimate	Std. Error	*t* value	Pr(>|t|)[a]
Injury	4 WAT	Two-leaf corn	0.04191	Intercept	3.5383	0.98	3.60	0.000483***
				Rate	1.7189	0.73	2.36	0.020376*
		Four-leaf corn	0.1296	Intercept	3.3419	1.06	3.14	0.00218**
				Rate	3.2089	0.79	4.06	9.59e-05***
Height	2 WAT	Two-leaf corn	0.02625	Intercept	53.311	1.73	30.81	<2e-16***
				Rate	−2.509	1.29	−1.95	0.05
		Four-leaf corn	0.004206	Intercept	116.002	3.82	30.36	<2e-16***
				Rate	−3.408	2.84	−1.20	0.23
Yield		Two-leaf corn	0.009251	Intercept	9062.19	395.39	22.92	<2e-16***
				Rate	−97.88	293.94	−0.33	0.74
		Four-leaf corn	0.01017	Intercept	9,011.62	386.72	23.30	<2e-16***
				Rate	52.12	286.14	0.18	0.86

[a]The asterisks indicate significance of the intercept value and significant differences among herbicide rates.

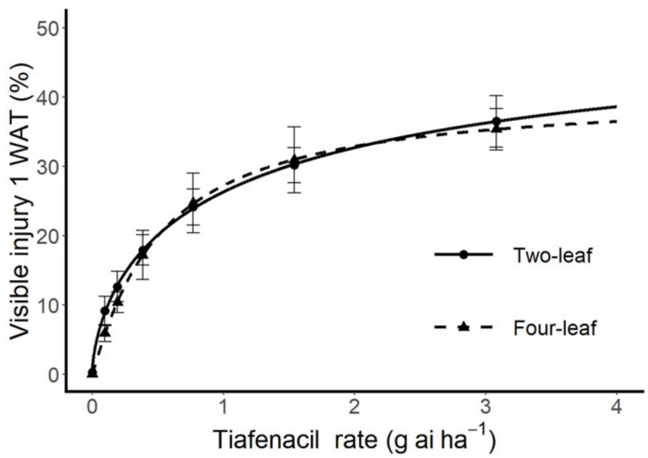

Figure 1. Corn injury 1 wk after treatment (WAT) as affected by tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.64 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

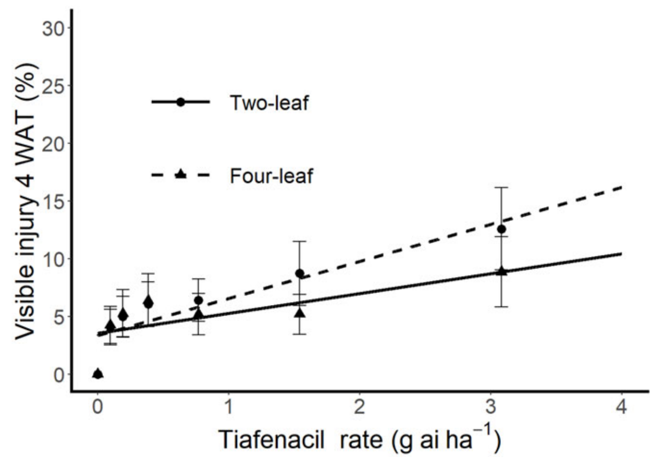

Figure 3. Corn injury 4 weeks after treatment (WAT) as impacted by tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.64 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

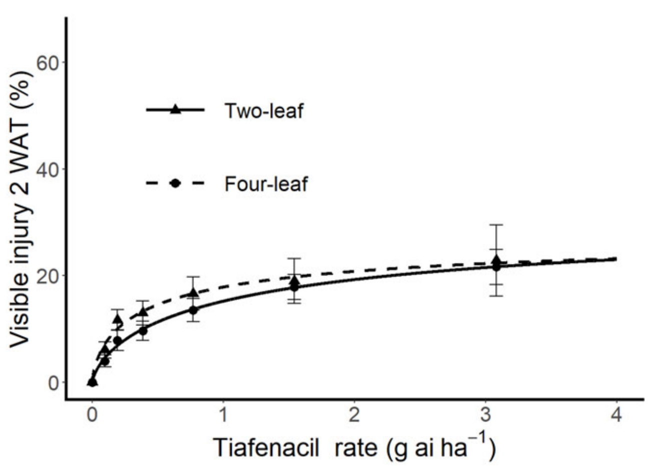

Figure 2. Corn injury 2 wk after treatment (WAT) as affected by tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.64 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

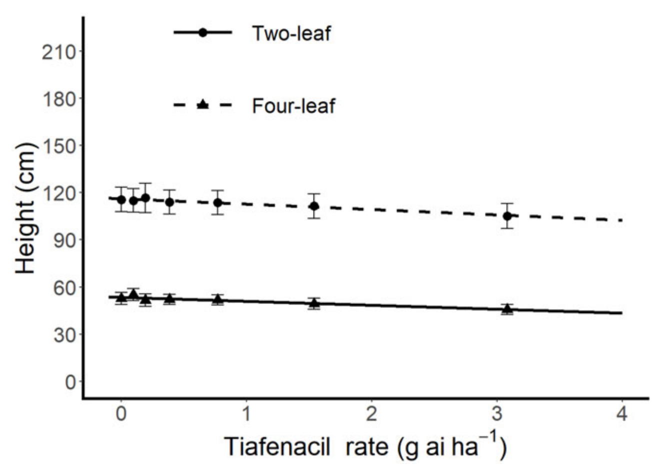

Figure 4. Corn height 2 wk after treatment (WAT) as affected by tiafencail at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.62 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

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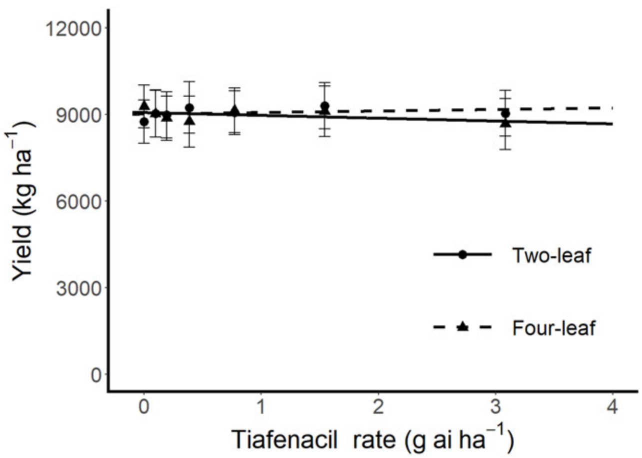

Figure 5. Corn yield as affected by tiafenacil at 0×, 1/8×, 1/16×, 1/32×, 1/64×, 1/128×, and 1/256× of a 24.62 g ai ha^{-1} use rate applied to two- or four-leaf corn for data pooled across locations of St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

Corn Yield

Similar to height, early-season injury was not manifested in yield reduction following tiafenacil exposure (Table 2). Nontreated corn yield averaged 9,062 and 9,011.6 kg ha^{-1} for the early and late growth stage timings (Figure 5). Yield following tiafenacil exposure ranged from 8,760.5 to 9,052.8 and 9,187.5 to 9,017.1 kg ha^{-1} at these respective growth stages. Sperry et al. (2019) reported that fomesafen reduced corn yield when applied at the V1 but not V3 or V5 growth stage, whereas paraquat reduced corn yield 1,740 kg ha^{-1} when applied at the V1 growth stage and 2,890 to 3,720 kg ha^{-1} at V3 to V7.

Practical Implications

Corn responded similarly at both growth stages evaluated in response to tiafenacil rates ranging from 12.5% to 0.4% of the lower end of the labeled rate range (24.64 g ai ha^{-1}). Early-season injury was evident quickly after application but lessened over time and was not manifested in height or yield reduction. In comparison to previous research conducted on fomesafen, the PPO-inhibiting herbicide (Sperry et al. 2019), corn response to off-target application of tiafenacil applied at rates evaluated would be similar between the two compounds, although the latter exhibits effective activity on grass species, whereas the former exhibits primarily broadleaf activity (Anonymous 2023b; Anonymous 2024d). Application of tiafenacil directly adjacent to corn in early vegetative stages of growth should be avoided, as injury will occur. Based on the results of this study and previous research (Sperry et al. 2019), tiafenacil appears to be a safer option for nonselective preplant weed control than paraquat in cotton or soybean fields in close proximity to emerged corn prior to the five-leaf growth stage. In cases where off-target tiafenacil movement does occur, however, impacted corn should be expected to fully recover with no impact on growth and yield assuming adequate growing conditions and agronomic/pest management practices are provided.

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Competing Interests. The authors declare none.

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