The *Journal of Cotton Science 28:58–64 (2024)*
http://journal.cotton.org, © The Cotton Foundation 2024

WEED SCIENCE

Impact of Reduced Rates of Tiafenacil on Early-Season Cotton (*Gossypium hirsutum* L.) Growth and Yield

Donnie K. Miller*, L. Tom Barber, Jason A. Bond, Lawrence E. Steckel, Daniel O. Stephenson IV, Matthew R. Foster, Thomas R. Butts, and Koffi Badou-Jeremie Kouame

ABSTRACT

Tiafenacil is a new nonselective protoporphyrinogen IX oxidase-inhibiting herbicide with both grass and broadleaf activity labeled for preplant application to corn, cotton, soybean, and wheat. Early-season cotton emergence and growth often coincides in the Mid-South with preplant herbicide application in later planted cotton and soybean, thereby increasing opportunity for off-target herbicide movement from adjacent fields. Field studies were conducted in 2022 to identify any deleterious impacts of reduced rates of tiafenacil (12.5 – 0.4% of the lowest labeled application rate of 24.64 g ai ha^{-1}) applied to one- to two-leaf cotton. Visual injury one week after treatment (WAT) with 1/8, 1/16, 1/32, and 1/64x rate of tiafenacil was 72, 54, 36, and 22%, respectively, whereas at four WAT these respective rates resulted in visual injury of 73, 67, 48, and 20%. Tiafenacil at these rates reduced cotton height 26 to 38% and 12 to 36% one and four WAT and seed cotton yield reduced 58, 38, 20, and 9%. Application of tiafenacil directly adjacent to cotton in early vegetative growth should be avoided as severe visual injury will occur. In cases where off-target movement occurs, impacted cotton should not be expected to recover fully and negative impact on growth and yield will be observed.

D.K. Miller*, LSU AgCenter Northeast Research Station, St. Jospeh, LA 71366; L.T. Barber, Univ. Arkansas System Division of Agriculture, Newport, AR 72112; J.A. Bond, Mississippi State Univ. Delta Research and Extension Center, Stoneville, MS 38776; L.E. Steckel, West Tennessee AgResearch and Education Center, Jackson, TN 38301; D.O. Stephenson IV, LSU AgCenter Dean Lee Research and Extension Center, Alexandria, LA 71302; M.R. Foster, LSU AgCenter Sugar Research Station, St. Gabriel, LA 70776; T.R. Butts, Purdue Univ. Dept. of Botany and Plant Pathology, West Lafayette, IN 47907; and K.B-J. Kouame, Kansas State Univ. Agricultural Research Center, Hays, KS 67601.
*Corresponding author: dmiller@agcenter.lsu.edu

Conservation Tillage. By 2022, approximately 87% of all cropland acres in the U.S. 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 percentage, continuous no-till accounted for one-third of the acreage. Use of conservation tillage in crop production can lead to a potential 2,888-million-liter reduction in diesel equivalents per year as well as a 7.7-million-metric-ton yearly reduction in associated emissions (Creech, 2022). Realized benefits of conservation tillage systems can include improved soil health, decreased erosion, maximized water infiltration, improved nutrient cycling, and a build-up in organic matter (Creech, 2022; Farmaha et al., 2021; Lal, 2015).

Conservation tillage systems rely 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 winter weed species encountered in corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean (*Glycine max* [L.] Merr.) production fields (Anonymous, 2023a; Barber et al., 2024; Bond et al., 2024; Steckel et al., 2024). Weed resistance issues and difficult to control species have necessitated identification of novel strategies and herbicides for continued successful preplant weed management in these production systems (Flessner and Pittman, 2019; Johanning et al., 2016; Vollmer et al., 2019; Westerveld et al., 2021a, b; Zimmer et al., 2018).

Tiafenacil Herbicide. Tiafenacil, a new protoporphyrinogen IX oxidase (PPO)-inhibiting herbicide developed by FarmHannong Co., Ltd., Korea, exhibits nonselective contact activity on both weed and crop species (Anonymous, 2023b; Park et al., 2018). PPO-inhibiting herbicides halt the production of protoporphyrin IX from protoporphyrinogen IX, eventually preventing chlorophyll and heme biosynthesis. The increase in protoporphyrin IX in the cytoplasm results in increased singlet oxygen, which leads to lipid peroxidation, cell membrane destruction, and ultimately plant death (Shaner, 2014). Tiafenacil is registered in the U.S. for preplant application to corn, cotton, soybean, and wheat (*Triticum aestivum* L.) as well as 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} alone 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).

Cotton and Off-Target Herbicide Impacts. Cotton was planted on more than four million hectares in the U.S. in 2023 (USDA NASS, 2023). Cotton emergence and early season growth often coincide with preplant herbicide applications made in preparation for later planting of cotton or soybean and often occurs in adjacent fields, thereby increasing opportunity for off-target herbicide movement. Drift or off-target movement was identified previously 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 a herbicide drift event.

Serious deleterious effects of simulated off-target movement of selective and nonselective herbicides to cotton at various growth stages have been demonstrated (Johnson et al., 2012; Manuchehri et al., 2020). Hurst (1982) investigated impacts of foliar application of normal use rates (0.2 – 0.6 kg ai ha^{-1}) and below normal use rates (0.07 and 0.1 kg ai ha^{-1}) of acifluorfen, a contact PPO-inhibiting herbicide similar to tiafenacil, to cotton at the cotyledon, five-, or eight-node growth stage. It was reported that acifluorfen at all rates above 0.07 kg ha^{-1} applied at the cotyledon stage severely reduced cotton stands. Additionally, rates of 0.1, 0.3, and 0.8 kg ha^{-1} reduced cotton yield at the cotyledon but not five- or eight-node growth stage. Miller et al. (2003) reported observing 20 to 30% and 6 to 16% injury to non-glufosinate tolerant cotton 2 wk after treatment (WAT) with 1/8 and 1/16x of an effective rate of 420 g ai ha^{-1} of glufosinate, a nonselective contact herbicide like tiafenacil. These applications resulted in significant plant population reduction but no reduction in seed cotton yield.

RESEARCH OBJECTIVES

As the use of tiafenacil for preplant application increases, so does the opportunity for off-target movement to young cotton plants growing in proximity to later planted soybean fields. To our knowledge no published information exists on the impact of tiafenacil on cotton growth and yield following foliar application at sublethal rates that can be encountered in off-target movement events. Therefore, the objective of this research was to determine any negative impacts of foliar application of tiafenacil to cotton.

MATERIALS AND METHODS

Field experiments were conducted in 2022 at the LSU AgCenter Northeast Research Station near St. Joseph, LA; the LSU AgCenter Dean Lee Research and Extension Center near Alexandria, LA; the University of Arkansas System Division of Agriculture Lon Mann Cotton Research Station in Marianna, AR; and the University of Tennessee AgResearch and Education Center in Milan, TN to determine the impact of reduced rates of tiafenacil on cotton 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 tiafenacil at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x rate applied to one- to two-leaf (lf) cotton. The 1x 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 0x rate and, therefore, was excluded from statistical analysis. Tiafenacil at designated rates was applied to one- to two-lf cotton variety DP 1646 B2XF near St. Joseph on 23 May, variety DP 2127 B3XF near Alexandria on 01 June, variety DP 2127 B3XF on 20 June in Marianna, and variety DP 1725 B2XF in Milan. This timing was selected as being the most likely to exist when burndown of late planted cotton or soybean ground normally occur in the Mid-South. Plots were maintained weed free at the St. Joseph and Alexandria locations with as needed applications of glyphosate at 1,120 g ai ha^{-1} plus glufosinate at 450 g ai ha^{-1}. Plots at Marianna were kept weed free with a PRE application of fluometuron at 1,680 g ai ha-1 plus fluridone 1,120 g ai ha^{-1}. Plots at Milan were kept weed free by hand-weeding. Parameter measurements included visual injury on a scale of 0 (no injury) to 100 (plant death) 1, 2, and 4 WAT; plant height at 2 and 4 WAT; and yield.

The four-parameter log-logistic model was fit to all parameters measured.

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

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}) (Tables 1, 2, 3). The goodness of fit of the four-parameter log-logistic model was evaluated using the root mean square error (RMSE) (Table 1).

$$MSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2}$$

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 are an indication of a better model fit to the data with values of 0 representing a perfect fit. The Nonlinear Least Squares (nls) function of the statistical package 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 were compared (Ritz et al., 2015) with no statistical differences detected between parameters of location for herbicide rates applied (data not shown). Therefore, data were pooled across locations for curve fitting. Model assumptions of homoscedasticity, independence, and normality were checked in each case.

Table 1. Nonlinear regression parameters for cotton visual injury 1, 2, and 4 weeks after treatment following application of tiafenacil at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022

Timing	Parameter estimates				Goodness of Fit
Weeks after application	c	d	b	e	RMSE (%)
1	2.0182	100.0000	-1.1069	0.6808	15.34773
2	-0.03565	100.00000	-1.25408	0.81754	14.37574
4	2.1187	74.7427	-2.3462	0.6166	20.17833

Table 2. Nonlinear regression parameters for cotton height 2 and 4 weeks after treatment following application of tiafenacil at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022

Timing	Parameter estimates				Goodness of Fit
Weeks after application	c	d	b	e	RMSE (cm)
2	31.965	56.8369	2.1594	0.3162	18.1457
4	62.9793	98.8669	2.186	0.5462	25.48703

Table 3. Nonlinear regression parameters for seed cotton yield after treatment following application of tiafenacil at at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022

Parameter estimates				Goodness of Fit
c	d	b	e	RMSE (kg ha^{-1})
417.237	3432.618	1.368	1.896	1171.453

RESULTS AND DISCUSSION

Cotton Injury. Cotton visual injury was characterized by necrotic speckling of leaves contacted at time of application and population reduction due to plant death at higher rates. Cotton was injured 84% at the highest tiafenacil rate applied (1/8x), with each successive rate reduction resulting in 72, 54, 36, 22, and 12% visual injury 1 WAT (Fig. 1). At 2 WAT visual injury was 71, 48, 23, 8, 2, and 0% at these same rates (Fig. 2). By 4 WAT, visual injury for each successive reduced rate was still 73, 67, 48, 20, 7, and 3% (Fig. 3). Hurst (1982) reported the PPO-inhibiting herbicide acifluorfen applied to cotyledon cotton at sublethal rates ranging from 0.1 to 0.8 kg ha^{-1} resulted in stands of 8 to 59% of that for an untreated control. Miller et al. (2003) reported that the nonselective contact herbicide glufosinate applied to 2-node non-glufosinate tolerant cotton resulted in 20 to 32% and 6 to 16% injury at a 1/8 and 1/16x reduced rate 14 DAT, respectively. In addition, the 1/8x rate reduced final plant population 9 to 14%. Tiafenacil can injure cotton leaves and is labeled as a harvest aid defoliant in the crop prior to harvest (Adams et al., 2022; Anonymous, 2023b).

Cotton Height. At 2 WAT, the three highest rates of tiafenacil applied reduced cotton height 38 to 43%, whereas the 1/64x rate resulted in a 26% reduction (Fig. 4). The lowest rates applied resulted in a 12 and 3% height reduction. At 4 WAT, height was reduced 25 to 36% by the three highest tiafenacil rates and 12% by the 1/64x rate (Fig. 5). The lowest rates applied reduced height no greater than 4%. The nonselective contact herbicide glufosinate reduced 2-node non-glufosinate cotton height 6 to 17% and 3 to 9% 30 DAT when applied at the 1/8 and 1/16x reduced use rates, respectively (Miller et al., 2003). These results and results from the current research indicate greater sensitivity of early-season cotton growth to off-target movement of tiafenacil compared to glufosinate.

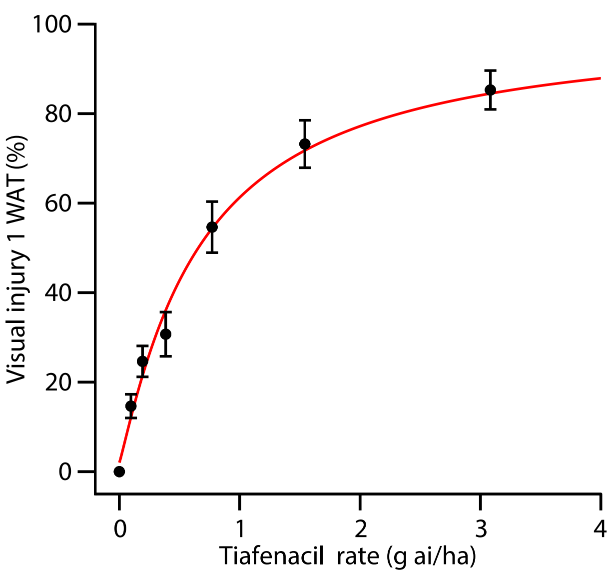

Figure 1. Cotton visual injury 1 week after treatment (WAT) as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

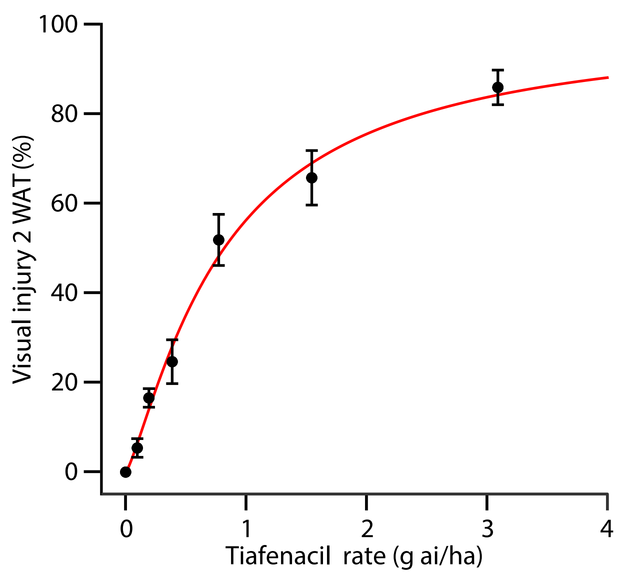

Figure 2. Cotton visual injury 2 weeks after treatment (WAT) as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

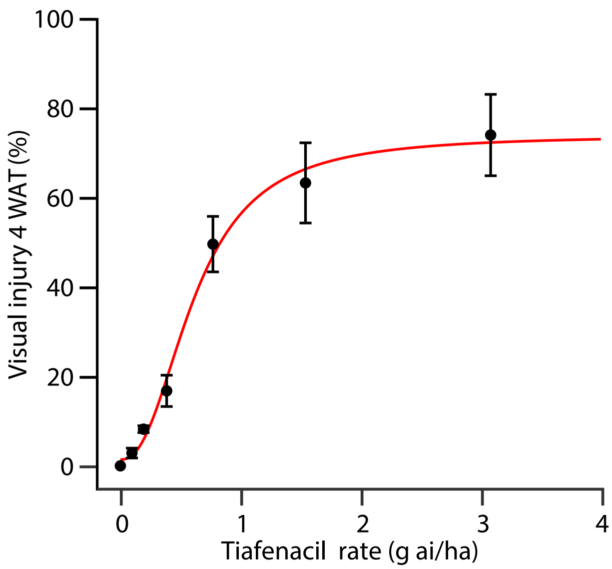

Figure 3. Cotton visual injury 4 weeks after treatment (WAT) as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

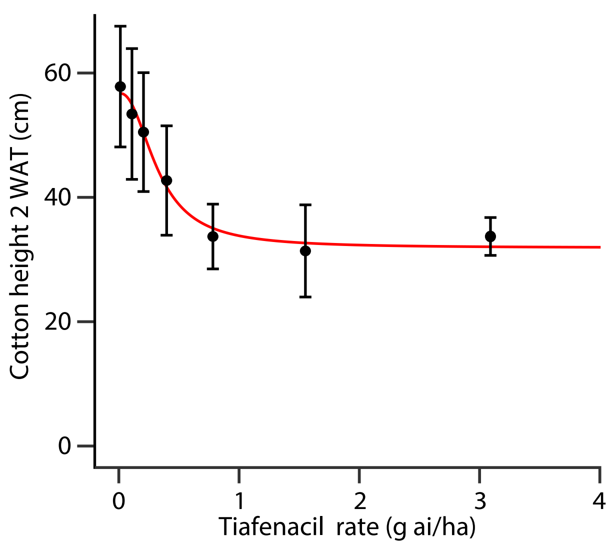

Figure 4. Cotton height 2 weeks after treatment (WAT) as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

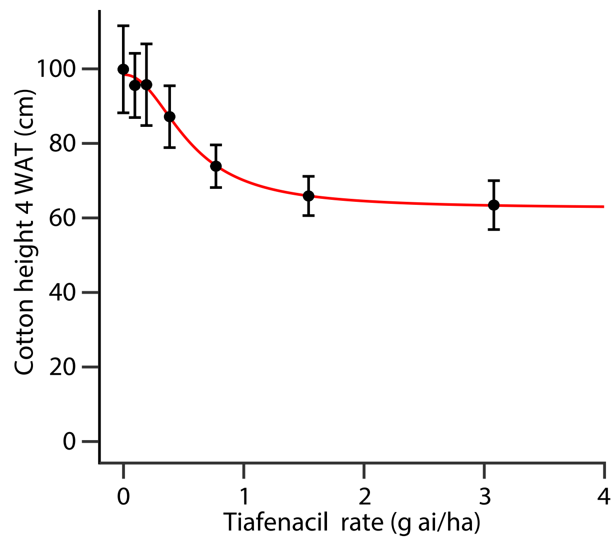

Figure 5. Cotton height 4 weeks after treatment (WAT) as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

Seed Cotton Yield. Cotton yield following exposure to tiafenacil at the 1/8x rate was reduced 58% (Fig. 6). Tiafenacil applied at 1/16, 1/32, and 1/64x rates resulted in reduced yield of 38, 20, and 9%, whereas the lowest rates reduced yield no greater than 1.5%. Negative impact of reduced rates of a contact PPO-inhibiting herbicide on cotton yield has been previously reported. Hurst (1982) found that the PPO-inhibiting herbicide acifluorfen applied at 1/2 and 1/3 of the lower end of a normal use rate range (0.2 – 0.6 kg ha^{-1}) resulted in cotton yield of 42 and 84% of nontreated control plants. Conversely, although resulting in significant early season injury and height reduction and reduced final plant population, non-glufosinate-resistant cotton treated with rates as high as 1/8 of an effective use rate of 420 g ai ha^{-1} was able to yield equal to that of a control. These results, in addition to previous research with acifluorfen and the current research, indicate that cotton is more sensitive to off-target movement from PPO-inhibiting herbicides at reduced rates in comparison to the nonselective contact herbicide glufosinate.

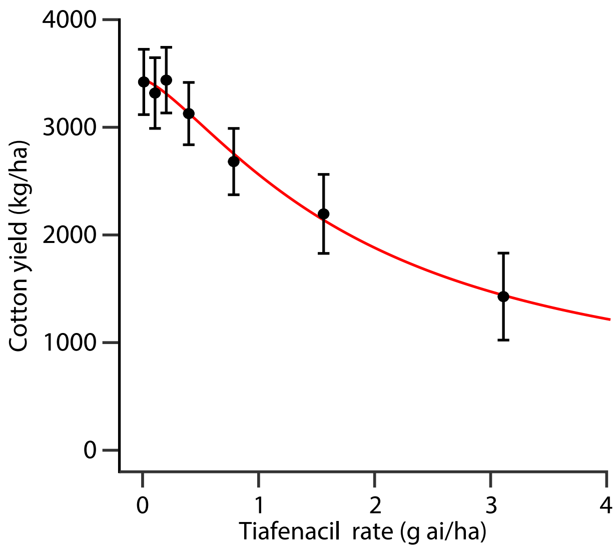

Figure 6. Seed cotton yield as impacted by reduced tiafenacil rate at 0x, 1/8x, 1/16x, 1/32x, 1/64x, 1/128x, and 1/256x of a 24.64 g ai ha^{-1} use rate applied to one- to two-leaf cotton for data collected at St. Joseph, LA, Alexandria, LA, Marianna, AR, and Milan, TN in 2022.

PRACTICAL IMPLICATIONS

In summary, severe visual cotton injury including plant death was observed early season in response to tiafenacil rates ranging from 12.5 to 1.6% of the lower end of the labeled rate range (26.64 g ai ha^{-1}) and did not lessen over time. This visual injury was also manifested in significant height and yield reduction. In comparison to previous research conducted on the PPO-inhibiting herbicide acifluorfen (Hurst, 1982), cotton season-long response to tiafenacil applied at rates evaluated would be similar between the two compounds. Application of tiafenacil directly adjacent to cotton in early vegetative stages of growth should be avoided. In cases where off-target tiafenacil movement occurs before the two-lf stage, injured cotton should not be expected to fully recover and negative impact on growth and yield will be observed.

REFERENCES

Adams, L., T. Barber, R. Doherty, T. Raper, D. Miller, and B. Peralisi. 2022. Use of Reviton as a cotton harvest aid. p. 121 In Proc. Beltwide Cotton Conf., San Antonio, TX. 4-6 Jan. 2022. Natl. Cotton Counc. Am., Memphis, TN. https://www.cotton.org/beltwide/proceedings/2005-2022/index.htm

Anonymous. 2023a. Louisiana suggested chemical weed management guide 2023. LSU AgCenter Publ. 1565. Available online at https://www.lsuagcenter.com/~/media/system/d/9/c/6/d9c65025862a52032feaf01c7f510f5a/p1565_la_suggestedchemicalweedguide_revlb0123pdf.pdf (verified 27 May 2024).

Anonymous. 2023b. Reviton herbicide label. Helm Agro US, Inc, Tampa FL 33602. Available online at https://www.cdms.net/ldat/ldH62016.pdf (verified 27 May 2024).

Barber, L.T., T.R. Butts, H.E. Wright-Smith, V. Ford, S. Jones, J.K. Norsworthy, N. Burgos, and M. Bertucci. 2024. Recommended chemicals for weed and brush control. Univ. Arkansas Syst. Div. Agric. Coop. Ext. Serv. MP44. Available online at https://www.uaex.uada.edu/publications/pdf/mp44/mp44.pdf (verified 26 May 2024).

Bond, J.A., L. Avila, T. Bararpour, H. Bowman, D.M. Dodds, J.T. Irby, E.J. Larson, B. Pieralisi, D.B. Reynolds, and B. Zurweller. 2024 Weed management suggestions for Mississippi row crops. Mississippi State Univ. Ext. Serv. Publ. 3171. Available online at https://www.mississippi-crops.com/wp-content/uploads/2023/12/2024-MS-Weed-MGT-1.pdf (verified 27 May 2024).

Butts, T.R., L.T. Barber, J.K. Norsworthy, and J. Davis. 2021. Survey of ground and aerial herbicide application practices in Arkansas agronomic crops. Weed Technol. 35:1–11. https://doi.org/10.1017/wet.2020.81

Butts, T.R., B.K. Fritz, K.B-J. Kouame, J.K. Norsworthy, L.T. Barber, W.J. Ross, G.M. Lorenz, B.C. Thrash, N.R. Bateman, and J.J. Adamczyk. 2022. Herbicide spray drift from ground and aerial applications: Implications for potential pollinator foraging sources. Sci. Rept. 12:18017. https://doi.org/10.1038/s41598-022-22916-4

Creech, E. 2022. Save money on fuel with no-till farming. USDA Farmers.Gov. US Dept. Agriculture. Available online at https://www.farmers.gov/blog/save-money-on-fuel-with-no-till-farming#:~:text=By%20transitioning%20from%20continuous%20conventional,per%20acre%20on%20fuel%20annually (verified 27 May 2024).

Farmaha, B.S., U. Sekaran, and A.J. Franzluebbers. 2021. Cover cropping and conservation tillage improve soil health in the southeastern US. Agronomy J. 114(1):296–316. https://doi.org/10.1002/agj2.20865

Flessner, M.L., and K.B. Pittman. 2019. Horseweed control with preplant herbicides after mechanical injury from small grain harvest. Agronomy J. 111(6):3274–3280. https://doi.org/10.2134/agronj2019.03.0174

Geddes, C.M., and M.M. Pittman. 2023. Glyphosate-resistant downy brome (*Bromus tectorum*) control using alternative herbicides applied postemergence. Weed Technol. 37:205–211. https://doi:10.1017/wet.2023.13

Hurst, H.R. 1982. Cotton (*Gossypium hirsutum*) response to simulated drift from selected herbicides. Weed Sci. 30:311–315. https://doi.org/10.1017/S0043174500040595.

Johanning, N.R., J.M. Young, and B.G. Young. 2016. Efficacy of preplant corn and soybean herbicides on Star-of-Bethlehem (*Ornithogalum umbellatum*) in no-till crop production. Weed Technol. 30:391–400. https://doi.org/10.1614/wt-d-15-00094.1

Johnson, V.A., L.R. Fisher, D.L. Jordan, K.E. Edmisten, A.M. Stewart, and A.C. York. 2012. Cotton, peanut, and soybean response to sublethal rates of dicamba, glufosinate, and 2,4-D. Weed Technol 26:195–206. https://doi.org/10.1614/wt-d-11-00054.1

Lal, R. 2015. Restoring soil quality to mitigate soil degradation. Sustainability 7(5):5875–5895. https://doi.org/10.3390/su7055875

Manuchehri, M.R., P.A. Dotray, J.W. Keeling, and S.A. Byrd. 2020. Non–2,4-D–resistant cotton response to glyphosate plus 2,4-D choline tank contamination. Weed Technol. 34:82–88. https://doi.org/10.1017/wet.2019.85

Miller, D.K., R.C. Downer, B.R. Leonard, E.M. Holman, and S.T. Kelly. 2003. Response of no-glufosinate resistant cotton to reduced rates of glufosinate. Weed Sci. 51:781–785. https://doi.org/10.1614/P2002-132

Mookodi, K.L., J.A. Spackman, and A.T. Adjesiwor. 2023. Urea amonnium nitrate as the carrier for preplant burndown herbicides. Agrosystems, Geosciences, and Environment 6(3):e20404. https://doi.org/10.1002/agg2.20404

Park, J., Y.O. Ahn, J.W. Nam, M.G. Hang, N. Song, T. Kim, and S.K. Sung. 2018. Biochemical and physiological mode of action of tiafenacil, a new protoporphyrinogen IX oxidase-inhibiting herbicide. Pesticide Biochem. Physiol. 152:38–44. https://doi: 10.1016/j.pestbp.2018.08.010

R Core Team, R. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Ritz, C., A.R. Kniss, and J.C. Streibig. 2015. Research methods in weed science: Statistics. Weed Sci. 63:166–187. https://doi.org/10.1614/WS-D-13-00159.1

Shaner, D. L. 2014. Herbicide Handbook. 10th ed. Weed Science Society of America, Champaign, IL.

Steckel, L., J. McNeal, T.C. Mueller, J. Reeves, B. Brown, T. Raper, M. Richmond, G.N. Rhodes Jr., and R.M Hayes. 2024. 2024 Weed control manual for Tennessee. Univ. Tennessee Ext. Inst. Agric. Publ. 1580. Available online at https://utbeef.tennessee.edu/wp-content/uploads/sites/127/2022/02/PB1580_2022_DCFLS.pdf (verified 27 May 2024).

United States Dept. Agriculture, National Agricultural Statistics Service [USDA NASS]. 2023. Prospective plantings (March 2023). Publ. ISSN:1949-159x. Available online at https://downloads.usda.library.cornell.edu/usda-esmis/files/x633f100h/rv044597v/gx41nz573/pspl0323.pdf (verified 27 May 2024).

Virk, S.S., and E.P. Prostko. 2022. Survey of pesticide application practices and technologies in Georgia agronomic crops. Weed Technol. 36:616–628. https://doi.org/10.1017/wet.2022.69

Vollmer, K.M., M.J. Van Gessel, Q.R. Johnson, and B.A. Scott. 2019. Preplant and residual herbicide application timings for weed control in no-till soybean. Weed Technol. 33:166–172. https://doi.org/10.1017/wet.2018.105

Westerveld, D.B., N. Soltari, D.C. Hooker, D.E. Robinson, and P.H. Sikkema. 2021a. Biologically effective dose of pyraflufen-ethyl/2,4-D applied preplant alone or mixed with metribuzin on glyphosate-resistant horseweed in soybean. Weed Technol. 35:824–829. https://doi:10.1017/wet.2021.46

Westerveld, D.B., N. Soltari, D.C. Hooker, D.E. Robinson, and P.H. Sikkema. 2021b. Efficacy of tiafenacil applied preplant alone or mixed with metribuzin for glyphosate-resistant horseweed control. Weed Technol. 35:817–823. https://doi.org/10.1017/wet.2021.39

Zimmer, M., B.G. Young, and W.G. Johnson. 2018. Weed Control with halauxin-methyl applied alone and in mixtures with 2,4-D, dicamba, and glyphosate. Weed Technol. 32:597–602. https://doi.org/10.1017/wet.2018.48