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Source: Weed Technology, 36(2) : 207-213

Published By: Weed Science Society of America

URL: https://doi.org/10.1017/wet.2022.7

Weed Technology

www.cambridge.org/wet

Research Article

Cite this article: Wasacz MH, Ward DL, VanGessel MJ, Besançon TE (2022) Sensitivity to sublethal rates of dicamba for selected mid-Atlantic vegetable crops. Weed Technol. **36**: 207–213. doi: 10.1017/wet.2022.7

Received: 25 October 2021
Revised: 29 January 2022
Accepted: 3 February 2022
First published online: 21 March 2022

Associate Editor:
Darren Robinson, University of Guelph

Nomenclature:
dicamba; sweet basil; *Ocimum basilicum* L.; bell pepper; *Capsicum annuum* L.; cucumber; *Cucumis sativus* L.; eggplant; *Solanum melongena* L.; kale; *Brassica oleracea* var. *acephala* DC.; lettuce; *Lactuca sativa* L.; lima bean; *Phaseolus lunatus* L.; pumpkin; *Cucurbita pepo* L.; snap bean; *Phaseolus vulgaris* L.; soybean; *Glycine max* (L.) Merr.; summer squash; *Cucurbita melopepo* L.; tomato; *Solanum lycopersicum* L.; watermelon; *Citrullus lanatus* (Thunb.) Matsum. & Nakai

Keywords:
auxin injury; dicamba; drift; leaf cupping; off-target injury; specialty-crop injury; volatility

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Sensitivity to sublethal rates of dicamba for selected mid-Atlantic vegetable crops

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Abstract

Dicamba is a synthetic auxin herbicide that may be applied over the top of transgenic dicamba-tolerant crops. The increasing prevalence of herbicide-resistant weeds has resulted in increased reliance on dicamba-based herbicides in soybean production systems. Because of the high volatility of dicamba it is prone to off-target movement, and therefore concern exists regarding its drift onto nearby specialty crops. The present study evaluates 12 mid-Atlantic vegetable crops species for sensitivity to sublethal rates of dicamba. Soybean, snap bean, lima bean, tomato, eggplant, bell pepper, cucumber, summer squash, watermelon, pumpkin, sweet basil, lettuce, and kale were grown in a greenhouse and exposed to dicamba at 0, 0.056, 0.11, 0.28, 0.56, 1.12, 2.24 g ae ha^{-1}, which is, respectively, 0, 1/10,000, 1/5,000, 1/2,000, 1/1,000, 1/500, and 1/250 of the maximum recommended label rate for soybean application (560 g ae ha^{-1}). Vegetable crop injury was evaluated 4 wk after treatment using visual rating methods and leaf deformation index measurements. Overall, snap bean was the most sensitive crop, with dicamba rates as low as 0.11 g ae ha^{-1} resulting in significantly higher leaf deformation levels compared with the nontreated control. Other Fabaceae and Solanaceae species also demonstrated high sensitivity to sublethal rates of dicamba with rates ranging 0.28 to 0.56 g ae ha^{-1} causing higher leaf deformation compared with the nontreated control. While cucumber, pumpkin, and summer squash were no or moderately sensitive to dicamba, watermelon showed greater sensitivity with unique symptoms at rates as low as 0.056 g ae ha^{-1} based on visual evaluation. Within the range of tested dicamba rates, sweet basil, lettuce, and kale demonstrated tolerance to dicamba with no injury observed at the maximum rate of 2.24 g ae ha^{-1}.

Introduction

The prevalence of glyphosate-resistant weeds such as Palmer amaranth (*Amaranthus palmeri* S. Watson), horseweed [*Conyza canadensis* (L.) Cronquist], and common ragweed (*Ambrosia artemisiifolia* L.) has led to the development and commercialization of alternative control technologies. In 2017, transgenic dicamba-resistant soybean was introduced to help manage glyphosate-resistant broadleaf weeds (Johnson et al. 2010; Soltani et al. 2020). This technology allows dicamba to be applied preplant in no-till production systems and as an over-the-top application in resistant soybean and cotton (*Gossypium hirsutum* L.) during mid-season.

Dicamba is a synthetic auxin herbicide that inhibits the development of the meristematic tissue in susceptible broadleaf plants (Chang and Vanden Born 1971; Griffin et al. 2013; McCown et al. 2018). Dicamba injury manifests as a distinctive leaf cupping deformation, as well as epinasty, swollen petiole bases, and terminal chlorosis (Griffin et al. 2013; McCown et al. 2018). Because doses below the recommended rate of dicamba can cause severe leaf deformation in many species, off-target movement of dicamba onto sensitive crops is a concern (Bohnenblust et al. 2016; Soltani et al. 2020). With increased use of dicamba products during the 2017 growing season, it was estimated that 1.5 million crop hectares were injured by dicamba off-target movement in the United States (WSSA 2018). Off-target deposition of dicamba can occur through wind-driven particle drift, vaporization, and spray equipment contamination. Particle drift occurs when spray particles are carried by wind, whereas vaporization occurs due to the high volatility of dicamba products (Behrens and Lueschen 1979; Egan and Mortensen 2012). Off-target deposition of dicamba can cause severe crop injury and lead to economic losses and potential legal conflicts between growers, applicators, and manufacturers.

The spread of glyphosate-resistant Palmer amaranth in the mid-Atlantic region has led to an increase in the acreage of dicamba-resistant soybean planted in New Jersey; estimated to be around 70% of 94,000 total soybean acres planted in 2021 (E. Guenther, personal communication; Heap and Duke 2018; Eklund 2021). Many vegetable fields in New Jersey are grown within close proximity to soybean fields, thereby increasing the potential for dicamba drift injury. Vegetable crops are of major concern for off-target movement due to their economic value, representing more than $13 billion in 2020 (USDA-NASS 2020) and sensitivity to dicamba (Colquhoun et al. 2014; Culpepper et al. 2018). Currently, data on relative sensitivities of vegetable crops to sublethal rates of dicamba are limited. Quantifying the sensitivity to dicamba of several economically important vegetable species may help specialty crops growers from the Mid-Atlantic region to more effectively design their planting strategies around dicamba-treated soybean fields. This research may also provide herbicide manufacturers with information on dicamba sensitivity that can be used for adapting restrictions on dicamba product labels to reduce the risk of off-target dicamba injury. Therefore, the objectives of this work were to provide information about the relative sensitivities to dicamba for several economically important vegetable crops grown in the mid-Atlantic United States.

Materials and Methods

Data presented here were collected from a greenhouse study that was designed to help narrow the scope of a complementary field study, the results of which will be subsequently published.

Plant Culture

This study was conducted in 2020 and 2021 in a greenhouse located on Rutgers University campus in New Brunswick, NJ. The photoperiod was 16 h with supplemental artificial lighting provided by a 400-W high-pressure sodium lamp when photosynthetically active radiation flow of natural light fell below 400 µE m^{-2} s^{-1}. Daily low temperatures ranged from 18 to 21 C with an average of 19 C. Daily high temperatures ranged from 21 to 24 C with an average of 22 C. Seeds of 16 vegetable crops (Table 1) were planted in commercial growing medium (SunGro® Horticulture Professional Growing Mix; Agawam, MA) in the greenhouse and hand watered daily. Approximately 70 seeds were planted for each crop, and 35 were selected for the study based on relative desired growth stage. Tomato, eggplant, sweet basil, and bell pepper were grown to 30 to 40 cm in height. Snap bean, lima bean, and pumpkin were grown to the cotyledon stage, at which no fully emerged true leaves were present. Soybean, cucumber, summer squash, and watermelon were grown up to the stage when 3 to 4 true leaves completely emerged. Kale and lettuce were grown until they were within 10 d of anticipated harvest. Cultivar selections are listed in Table 1, with the exception of 'Premier' kale, 'Rutgers Devotion DMR' sweet basil, and 'Butterhead' lettuce. Tomato, eggplant, sweet basil, and bell pepper were grown in 3.7-L pots; whereas lettuce, kale, Cucurbitaceae, and Fabaceae crops were grown in 10-cm-square pots. Potted plants were fertilized weekly with Jack's Professional General-Purpose 20-20-20 fertilizer (JR Peters, Inc., Allentown, PA) with nitrogen at 750 ppm.

Herbicide Treatments

To simulate potential active ingredient concentrations found in particle drift, seven sublethal rates of dicamba were applied to the vegetable crop species. Dicamba (XtendiMax®; Bayer Crop Science, Research Triangle Park, NC) doses were 0, 0.056, 0.11, 0.28, 0.56, 1.12, and 2.24 g ae ha^{-1}, which are, respectively, 0, 1/10,000, 1/5,000, 1/2,000, 1/1,000, 1/500, and 1/250 of the maximum recommended label rate for soybean application (560 g ae ha^{-1}). The dicamba rate of 0.056 g ae ha^{-1} corresponded to the lowest observed effect for exposure to sensitive soybean plants (Egan and Mortensen 2012). Dicamba was applied using a single-nozzle track spray chamber (Generation 3, SB8-211; DeVries Manufacturing, Hollandale, MN) equipped with an 8002EVS flat-fan Teejet® nozzle (TeeJet, Glendale Heights, IL), delivering 140 L ha^{-1} at 310 kPa.

Herbicide was applied based on the estimation of phenotypic growth stage at which the vegetable crop would be during mid-June in New Jersey, when soybean is typically treated with dicamba. Growth stages were chosen based on the recommendations made by a panel of Rutgers Cooperative Extension vegetable specialists (W Kline, M InfanteCasellas, and R VanVranken, personal communication). The experiment was arranged in a randomized complete block design with five replications per treatment. This study was repeated in the winters of 2020 and 2021.

Visual Evaluations of Leaf Deformation

Individual plants were visually evaluated for percent leaf area reduction caused by dicamba-induced leaf deformation compared with nontreated control foliage. Visual evaluations were conducted weekly up to 4 wk after treatment (WAT) using a scale from 0 (flat leaf) to 100 (no measurable leaf area) based on an integrated estimation of leaf cupping, leaf strapping, and leaf crinkling. In these studies, dicamba injury primarily manifested as leaf cupping with secondary symptoms that included leaf crinkling and leaf strapping. Visual evaluations included only foliage that emerged after the dicamba application, since dicamba accumulates in meristematic plant tissue and injury manifests only in the uppermost leaves (Chang and Vanden Born 1971; Griffin et al. 2013; McCown et al. 2018).

Leaf Deformation Index Evaluations

Leaf deformation index (LDI) was calculated for the first that emerged leaf after dicamba application on each individual plant (Wasacz et al. 2021). The LDI method is intended to measure the amount of leaf deformation that occurs after a dicamba treatment, but does not account for leaf size differences as a result of dicamba application. Four weeks after treatment, the first leaf to fully emerge immediately after dicamba treatment was removed and LDI was measured. Leaf area and "leaf shadow" were measured using a Perfection V800 photo scanner (Epson, Los Alamitos, CA) and simultaneously computed by WinRhizo Arabidopsis 2017 software (Regent Instruments Inc., Quebec City, QC, Canada). Individual leaves in their natural configuration were placed onto the scanner bed with the adaxial surface facing downward, as to mimic a light source hitting the leaf surface, and "leaf shadow" was measured. Next, the same leaf was flattened using a clear plastic tray and the leaf area was measured. LDI was then calculated according to Equation 1:

$$LDI = \left[\left(\frac{A_s}{A_f}\right)\right] \times 100 \qquad [1]$$

where A_s is the leaf shadow area and A_f is leaf flattened area. LDI evaluations use leaf area measurements to quantify the amount of leaf deformation independent of leaf area reduction. LDI values were subtracted from 100 to make comparisons with visual evaluations clearer.

Table 1. Minimum effective rate for LDI and visual estimation of leaf deformation, and area under the curve for visual estimation of leaf deformation for vegetable species sprayed with sublethal dicamba rates ranging from 0 to 2.24 g ae ha^{-1}.[a]

Crop	Cultivar	Botanical family[b]	MER for visual deformation[c]	MER for LDI	AUC[d]
			g ha^{-1}		
Snap bean	'Caprice'	Fab	0.11	0.11	251 A
Eggplant	'Santana'	Sol	0.11	0.56	220 Ab
Soybean	'SG 4078 GT/LL'	Fab	0.28	0.28	174 Bc
Lima bean	'Fordhook Bush 242'	Fab	0.28	0.56	155 C
Snap bean	'Bush Blue Lake 274'	Fab	0.28	0.56	164 C
Cucumber	'Burpless Beauty'	Cuc	0.28	1.12	146 C
Tomato	'Roma'	Sol	0.28	2.24	165 C
Eggplant	'Black Beauty'	Sol	0.56	0.28	161 C
Bell pepper	'Great Stuff Hybrid'	Sol	0.56	1.12	84 D
Watermelon	'Crimson Sweet'	Cuc	0.56	1.12	88 D
Summer squash	'Saffron Prolific Straightneck'	Cuc	1.12	2.24	33 E
Cucumber	'Python'	Cuc	1.12	None	16 E
Pumpkin	'Jack-o-lantern'	Cuc	2.24	2.24	16 E

[a]Species are listed from most to least sensitive based on visual deformation ratings.
[b]Abbreviations: Sol, Solanaceae; Fab, Fabaceae; Cuc, Cucurbitaceae; MER, minimum effective rate; LDI, leaf deformation index; AUC, area under the curve.
[c]MER is the lowest rate with mean visual deformation significantly different from control according to Dunnett's test (α = 0.05).
[d]Means with no letters in common are significantly different at α = 0.05 according to Tukey's honestly significant difference test (α = 0.05).

Statistical Analysis

All statistical analyses were performed using SAS software version 9.4 (SAS Institute, Cary, NC). Species were analyzed separately, but both years were analyzed together due to preliminary analysis indicating that there was no significant interaction effect between year and dicamba rate on the data.

The LDI data were subjected to ANOVA using the GLIMMIX procedure to test for the effects of dicamba rate. Fixed effects in the model were year and dicamba rate. Random effects in the model were blocks within years. The adequacy of the model was assessed using plots of studentized residuals and quantile-quantile plots. Due to the heterogeneity of the variances, the visual deformation rating data were subjected to ANOVA using a randomization test and the same model in GLIMMIX (Cassell 2002). Dunnett's test was used to determine the minimum effective rate (MER), which is defined as the lowest concentration of dicamba that was significantly different form the nontreated control group for visual deformation ratings and LDI (α = 0.05). To compare crops for overall sensitivity the area under the curve of visual deformation across dicamba rates in each block was calculated using the EXPAND procedure and the trapezoid rule for each crop. The calculated areas were then subjected to ANOVA using the GLIMMIX procedure. Least-squares means for each crop were then grouped using Tukey's honestly significant difference test (α = 0.05).

For species with significant differences among dicamba rate means, a nonlinear four-parameter logistic curve was used to help visualize the relationship between dicamba rate and leaf deformation according to Equation 2:

$$Y = \alpha + (\delta - \alpha)/\{1 + (x/\theta)^{\beta}\} \quad [2]$$

where Y is the dependent variable (visual leaf deformation), x is the dicamba rate expressed in mg ae ha^{-1}, α is the upper limit of the dose response curve, δ is the lower limit of the dose response curve, θ is the EC_{50} inflection point (i.e., dicamba rate corresponding to 50% response between upper and lower limit), and β is the slope around the point of inflection (Dmitienko et al. 2007). Data were plotted in SigmaPlot 12.0 (Systat Software Inc., San Jose, CA). For this model fitting, visual deformation ratings were selected over LDI because visual ratings are standard field evaluation widely used by weed scientists for assessing herbicide tolerance of various crops.

Results and Discussion

Cucurbitaceae

The MERs for visual evaluations were 0.28, 1.12, 1.12, 2.24, and 0.56 g ae ha^{-1} for 'Burpless Beauty' cucumber, 'Python' cucumber, summer squash, pumpkin, and watermelon, respectively. The MER for LDI measurements were 1.12, 2.24, 2.24, and 1.12 g ae ha^{-1} for Burpless Beauty cucumber, summer squash, pumpkin, and watermelon, respectively. For Python cucumber, there was no detectable MER for LDI (Table 1).

Overall, Cucurbitaceae crops demonstrated a wide range of visual responses to sublethal dicamba rates (Figure 1A). While cucumber Burpless Beauty was highly sensitive, with 60% leaf deformation at the highest rates of dicamba, Python showed very low sensitivity to sublethal rates of dicamba, with <10% visual leaf deformation at any rate (Figure 1A). Additionally, the Burpless Beauty cucumber showed a gradual increase in leaf deformation across higher rates, with no plateau, even at the highest rate applied (Figure 1A). However, Python cucumber demonstrated leaf deformation that increased rapidly from 1.00 to 1.30 g ae ha^{-1}, where it reached a maximum at 7% visual deformation (Figure 1A). In a study by Hand et al. (2021) in which 1/250th of the labeled rate of dicamba (2.24 g ae ha^{-1}) was applied, 'Impact' and 'Bristol' cucumbers visually evaluated 9 d after application demonstrated 10% visual injury on average, thereby demonstrating the possibility that sensitivity differences exist among cultivars of the same species.

In the present study, pumpkin was one of the least sensitive cucurbit species, exhibiting <10% visual deformation at the highest rate applied. The logistic curve for pumpkin remained at 0% injury until the dose reached about 1.20 g ae ha^{-1}, where it increased and approached a maximum at 7% visual deformation (Figure 1A). Summer squash responded similarly to pumpkin, but exhibited 10% visual deformation at the second highest rate (1.12 g ae ha^{-1}), suggesting slightly higher dicamba sensitivity than pumpkin (Figure 1A). The summer squash curve showed a gradual increase starting near 0.30 g ae ha^{-1}, without reaching a maximum within

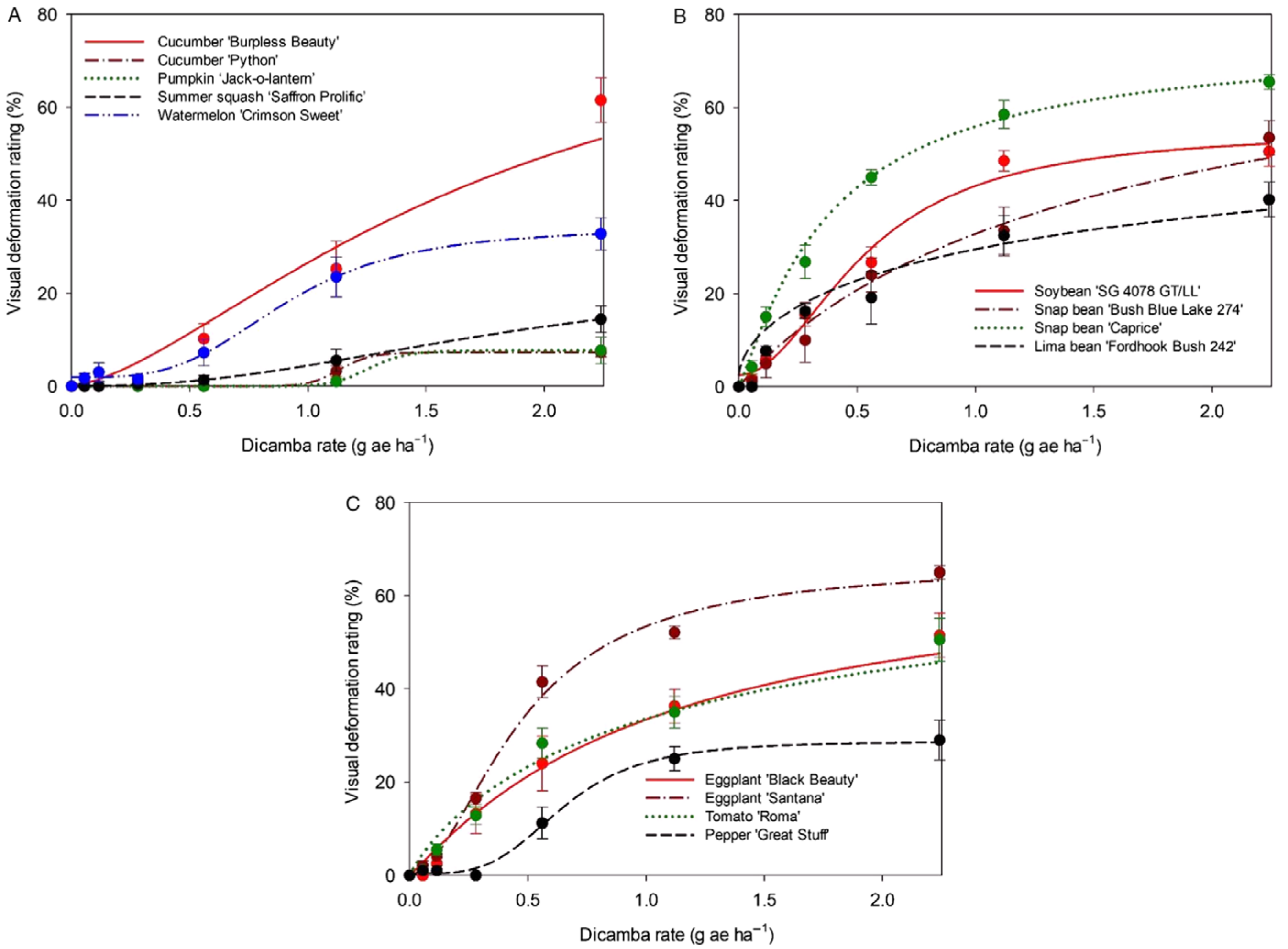

Figure 1. Predicted visual estimate of deformed leaf area of Cucurbitaceae crops (A), Fabaceae crops (B), and Solanaceae crops (C) 28 d after treatment in response to 0, 0.056, 0.11, 0.28, 0.56, 1.12, and 2.24 g ae ha^{-1} rates of dicamba.

the experimental range (Figure 1A). Watermelon showed significant sensitivity to dicamba with unique symptoms at rates as low as 0.056 g ae ha^{-1} when evaluated visually. While all other cucurbit crops showed leaf cupping, watermelon leaves developed an epinastic response to dicamba associated with venal feathering, crinkling of the adaxial leaf surface, and overall leaf fingering (Figure 2D). At the highest sublethal rate, watermelon exhibited 30% visual deformation (Figure 1A) and 20% LDI on average. The logistic curve for watermelon shows slightly higher levels of visual deformation than other cucurbit crops at the low rates, with a gradual increase in visual deformation beginning near 0.40 g ae ha^{-1} until the curve flattened near 2.10 g ae ha^{-1} and 30% visual deformation (Figure 1A). In comparison, a previous study demonstrated that watermelon treated with 1/250th of the dicamba label rate (2.24 g ae ha^{-1}) exhibited 17% visual injury on average when evaluated 2 WAT (Culpepper et al. 2018).

Fabaceae

The MER for visual evaluations were 0.28, 0.11, 0.28, and 0.28 g ae ha^{-1} for soybean, 'Caprice' snap bean, 'Bush Blue Lake 274' snap bean, and lima bean, respectively. The MER for LDI were 0.28, 0.11, 0.56, and 0.56 g ae ha^{-1} for soybean, Caprice snap bean, Bush Blue Lake 274 snap bean, and lima bean, respectively (Table 1).

All Fabaceae species were highly sensitive to sublethal rates of dicamba. Unlike Cucurbitaceae species, Fabaceae species did not differ greatly in MER for visual deformation. Caprice snap bean was the most sensitive cultivar, having the lowest MER (0.11 g ae ha^{-1}) of all crops tested in this study for both methods of dicamba injury rating (Table 1) and showing greater than 60% visual deformation at the highest dicamba rate. The logistic curve for Caprice snap bean showed a sharp increase in leaf deformation from 0 to 1.00 g ae ha^{-1}, where the curve continued to increase steadily without reaching a maximum in the experimental range (Figure 1B). While Bush Blue Lake 274 snap beans were less sensitive to dicamba, both snap bean cultivars exhibited high levels of leaf deformation in both methods of evaluation, with <40% visual deformation and <20% LDI on average. The curve for Bush Blue Lake 274 snap bean showed a uniform increase across dicamba rates tested in this study, but did not reach an asymptote within the experimental range (Figure 1B).

Lima bean was the least sensitive Fabaceae species, but showed 50% visual leaf deformation (Figure 1B) and greater than 15% LDI at the highest dicamba rate applied. In this study, the curve for lima bean displayed a gradual increase in leaf deformation, but never reached a maximum in the tested range (Figure 1B). Soybean was more sensitive than lima bean and Bush Blue Lake 274 snap bean, but less sensitive than Caprice snap bean. The logistic curve

Figure 2. Pictures of the first emerged leaf for 'Fordhook Bush 242' Lima bean (A), 'Great Stuff Hybrid' bell pepper (B), 'Black Beauty' eggplant (C), 'Crimson Sweet' watermelon (D), 'Roma' tomato (E), and 'Burpless Beauty' cucumber (F) 28 d after application of dicamba at 2.24 g ae ha^{-1}.

for soybean increased rapidly until it reached 2.00 g ae ha^{-1}, where the curve approached a maximum near 55% visual deformation (Figure 1B). A meta-analysis of 11 soybean field studies by Kniss (2018) concluded that injury could be detected visually at rates as low as 1/20,000th of the label rate of dicamba (0.03 g ae ha^{-1}). Additionally, a previous study showed that 1/400th of the label rate of dicamba (1.40 g ae ha^{-1}) applied to snap bean resulted in 43% visual injury 18 d after treatment (DAT) as well as a significant yield reduction, further emphasizing the sensitivity of Fabaceae crops to low doses of dicamba (Colquhoun et al. 2014).

Solanaceae

The MER for injury was 0.56, 0.56, 0.11, and 0.28 g ae ha^{-1} for bell pepper, 'Black Beauty' eggplant, 'Santana' eggplant, and tomato, respectively. The MER for LDI was 1.12, 0.28, 0.56, and 2.24 g ae ha^{-1} for bell pepper, Black Beauty and Santana eggplant, and tomato, respectively (Table 1).

Bell pepper was the least sensitive Solanaceae species, with no more than 30% visual deformation (Figure 1C) and <30% LDI at the highest rate. A previous study demonstrated that 1/200th of the label rate of dicamba (2.80 g ae ha^{-1}) applied to bell pepper resulted in 10% visual injury 28 DAT (Mohseni-Moghadam and Doohan 2015). In this study, the logistic curve for bell pepper shows a rapid increase in leaf deformation from about 0.30 to 1.20 g ae ha^{-1}, where the curve flattened near 25% (Figure 1C). Additionally, Santana eggplant was the most sensitive cultivar and crop in this family based on area under the curve of visual estimation of leaf deformation (Table 1) with peak visual injury increasing up to 60% at the highest dicamba rate (Figure 1C). Both eggplant cultivars had the highest LDI values in the study, >45% at the highest rate of dicamba, due to the intense leaf cupping observed. The logistic curve for Santana eggplant showed a rapid increase in visual deformation from 0 to 1.00 g ae ha^{-1}, where the curve begins to flatten but does not reach a maximum within the experimental range (Figure 1C). On the other hand, the curves for Black Beauty eggplant and tomato demonstrated a gradual increase beginning at 0, despite both curves not reaching a maximum within the experimental range (Figure 1C). However, the LDI data showed that tomato was only significantly different from the nontreated control at the highest sublethal rate, despite the high visual deformation assessment. This discrepancy may be attributed to the naturally crinkled leaf morphology of tomato plants, making the LDI rating not as useful as those species with naturally flat leaves (e.g., eggplant). Previous literature has demonstrated that tomato plants are highly sensitive to dicamba injury, with only 0.82 g ha^{-1} of dicamba causing 10% visual injury 21 DAT (Knezevic et al. 2018).

Lettuce, Kale, and Sweet Basil

No visual leaf deformation in response to dicamba application was detected in lettuce, kale, or sweet basil based on either visual ratings or LDI (data not shown). Thus, sensitivity to rates of dicamba equal to or lower than 2.24 g ae ha^{-1} is limited or null for these crops when reaching a growth stage close to optimal development for harvest. Previous research with potted 'Stella' lettuce found that plants sprayed 30 d after transplanting could tolerate dicamba up to 16.8 g ae ha^{-1} and showed complete recovery 28 DAT from dicamba-induced phytotoxicity with no biomass reduction compared to untreated plants (Roesler et al. 2020). However, lettuce death was noted for doses of 67.2 g ae ha^{-1} or greater. Chen (2021) observed varietal difference in the susceptibility of lettuce to dicamba injury with no significant yield reduction for 'Vulcan' lettuce exposed to dicamba dose of 23 g ae ha^{-1}, whereas the same rate caused nearly 50% yield loss in 'Green Forest' lettuce. Yield response was also affected by lettuce growth stage in 2020 with Green Forest and Vulcan varieties not showing yield reduction when treated at the mature stage with doses of 140.5 and 56 g ae ha^{-1}, whereas 'Allstar' yield significantly decreased. Lettuce had been considered to be highly susceptible to dicamba drift by authors mentioned previously. However, none of previous studies investigated dicamba rates lower than 0.56 g a.i. ha^{-1} in contrast to the present study, and Chen (2021) reported model-predicted dicamba dose ranging 4.4 to 57.7 g ae ha^{-1} for reaching 5% injury 7 DAT for three lettuce varieties treated at the mature stage. These doses are beyond rates tested in this study and confirm greater dicamba tolerance of lettuce at the mature stage in comparison to other vegetable crops investigated here.

Consistent with results of this study observed on kale, Nascimento et al. (2020) did not report any injury on greenhouse-grown cabbage 'Astrus Plus' (*Brassica oleracea* var. *capitata* L.) sprayed with dicamba at 2.4 to 96 g ae ha^{-1} when plants had two pairs of true leaves. Authors conducted a similar field study and reported injury averaging 20% only for doses equal or greater than 96 g ae ha^{-1} without resulting in yield reduction. Horseradish [*Armoracia rusticana* (L.) Britton] also belongs to the Brassicaceae family and has been shown to tolerate dicamba with no significant yield and height reduction at doses lower than 280 g ae ha^{-1} when dicamba was applied 45 d after seeding (Wiedau 2017).

To our best knowledge, no previous literature exists on sweet basil response to sublethal dicamba rates. Additional evaluations under greenhouse and field conditions should be conducted to determine whether dicamba tolerance noted for lettuce, kale, and sweet basil in this study would be confirmed for applications at earlier growth stages or is a response to a reduction in new shoots production associated with plant aging.

In this greenhouse study, two different rating methods were used to calculate the MER and evaluate foliar injury in vegetable crops to sublethal rates of dicamba. Visual deformation ratings tended to detect higher levels of injury at lower rates than the LDI method. While visual deformation ratings are efficient and robust to crop species differences in leaf deformation morphology, the LDI method provides a simple assessment of leaf deformation that removes rater bias (Wasacz et al. 2021). The LDI method was also included in this study to further assess the value of this method.

Overall, the data indicate that Fabaceae and Solanaceae crops tend to be more sensitive than Cucurbitaceae crops within the range of dicamba rates tested in this study. Solanaceae and Fabaceae experienced higher levels of injury at lower sublethal rates compared to Cucurbitaceae crops for both evaluation methods, indicating that these families are at higher risk for potential dicamba drift injury. Through future studies, these crops and cultivars may be tested at other geographic locations, including field locations, to see how sensitivity differs in a range of environmental conditions. Additionally, LDI analysis can be further performed on multiple tissue samples per observational unit. Future studies may also aim to quantify sensitivity of these crops and different cultivars at other rates and application timings. Since significant differences were observed between cucumber, eggplant, and snap bean cultivars, it is possible that some cultivars may be more sensitive to dicamba drift injury than others. The information obtained in the present study can be used to make future management decisions for growers, applicators, and consultants to plan their planting strategies near dicamba treated fields to mitigate the risk of dicamba volatilization onto sensitive vegetable crops.

Acknowledgments. We acknowledge funding support for this research by Bayer Crop Science and the Rutgers New Jersey Agricultural Experiment Station. We thank Baylee Carr, Tim Jensen, Suzanne Polashock, David Mayonado, Corrie Hopkins, and the crew at the Rutgers University NJAES greenhouses for their technical support. We also thank Lynn Sosnoskie and Andy Wyenandt for reviewing the manuscript. No conflicts of interests have been declared.

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