Response of Common Garden Annuals to Sublethal Rates of 2,4-D and Dicamba with or without Glyphosate

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SUMMARY. An experiment was conducted in 2017 and 2018 to determine the sensitivity of common garden annuals to sublethal rates of 2,4-dichlorophenoxyacetic acid (2,4-D) and dicamba with or without glyphosate. Sublethal rates corresponding to 1/10 $\times$, 1/100 $\times$, and 1/300 $\times$ of the full labeled rate (1 $\times$) of 2,4-D (1.0 lb/acre), 2,4-D plus glyphosate (1.0 lb/acre plus 1.0 lb/acre), dicamba (0.5 lb/acre), and dicamba plus glyphosate (0.5 lb/acre plus 1.0 lb/acre) were applied to ‘Prelude’ wax begonia (*Begonia $\times$ semperflorens-cultorum*), ‘Wizard’ coleus (*Solenostemon scutellarioides*), ‘Pinto’ zonal geranium (*Pelargonium $\times$ hortorum*), ‘Dazzler’ impatiens (*Impatiens walleriana*), ‘Bonanza’ french marigold (*Tagetes patula*), ‘Hurrah’ petunia (*Petunia hybrida*), ‘Titan’ madagascar periwinkle (*Catharanthus roseus*), and ‘Double Zahara’ zinnia (*Zinnia marylandica*). Visible injury, plant height, number of flowers, and dry weight were recorded at specific time intervals after treatment. When averaged across all annual plant species, the 1/10 $\times$ rate of 2,4-D plus glyphosate resulted in 51% injury 28 days after treatment, whereas the 1/10 $\times$ rate of dicamba plus glyphosate resulted in 43% injury. Treatments causing the greatest injury also resulted in the greatest reduction of dry weight, height, and flower production. Coleus was the most sensitive species in the study; dry weight was reduced by 16% and 18% compared with the nontreated controls from 1/300 $\times$ rates of 2,4-D plus glyphosate and dicamba plus glyphosate, respectively. French marigold and zonal geranium had greater sensitivity to treatments containing 2,4-D, but coleus and zinnia had greater sensitivity to treatments containing dicamba. Petunia exhibited a high tolerance to 2,4-D or dicamba applied alone (>6% injury) but was highly sensitive when glyphosate was added to 2,4-D and dicamba (<65% injury). The 1/100 $\times$ and 1/300 $\times$ rates that are likely to equate to sublethal rates in field settings, resulted in less than 15% injury across all flower species except coleus and petunia.

The prevalence of herbicide-resistant weeds in U.S. corn (*Zea mays*), soybean (*Glycine max*), and cotton (*Gossypium hirsutum*) production systems has left farmers with a limited number of weed control options (Norsworthy et al., 2012). To combat herbicide-resistant weeds, agrochemical companies have developed soybean and cotton that are resistant to 2,4-dichlorophenoxyacetic acid (2,4-D) and dicamba

(Behrens et al., 2007; Wright et al., 2010). Recent deregulation of dicamba and 2,4-D resistant crop cultivars in the United States allows farmers to use these technologies to control herbicide-resistant weeds (U.S. Department of Agriculture, 2014, 2015). Previous research has shown that dicamba and 2,4-D are effective on waterhemp (*Amaranthus tuberculatus*), horseweed (*Conyza canadensis*), palmer amaranth

(*Amaranthus palmeri*), and giant ragweed (*Ambrosia trifida*), which are some of the most problematic weed species encountered in U.S. crop production systems (Craigmyle et al., 2013; Johnson et al., 2010; Kruger et al., 2010; Robinson et al., 2012; Shergill et al., 2017; Spaunhorst et al., 2014; Van Wyche, 2017). It is likely that the adoption of 2,4-D and dicamba resistant crops will result in an increased number of applications of 2,4-D and dicamba with or without glyphosate in the near future which could, in turn, result in increased off-target movement of 2,4-D or dicamba with or without glyphosate to neighboring plant species, including homeowners’ annual gardens or to wholesale greenhouses and nurseries.

The ability of 2,4-D and dicamba to move off-target and cause damage to nearby sensitive plants can be influenced by a variety of factors, such as wind speed, nozzle type, boom height, and herbicide formulation (Alves et al., 2017; Egan and Mortensen, 2012; Holterman et al., 1997; Nordby and Skuterud, 1974; Sosnoskie et al., 2015; Wang and Rautmann, 2008). Several studies have shown that higher wind speeds can result in greater off-target movement (Alves et al., 2017; Nordby and Skuterud, 1974; Wang and Rautmann, 2008; Wolf et al., 1993). For example, Alves et al. (2017) found that when wind speeds were increased from 1 to 5 m·s⁻¹, greater downwind detection of dicamba occurred. Wolf et al. (1993) reported that 1.8% to 16.0% of the applied 2,4-D moved off-target with wind speeds of 9 to 30 km·h⁻¹. New formulations of 2,4-D choline and dicamba set restrictions on their labels pertaining to maximum wind speeds at which these products

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
0.0254	mil(s)	mm	39.3701
1.6093	mph	km·h ⁻¹	0.6214
0.4470	mph	m·s ⁻¹	2.2369
28.3495	oz	g	0.0353
70.0532	oz/acre	g·ha ⁻¹	0.0143
1	ppm	mg·L ⁻¹	1
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

may be applied, restricting applications to wind speeds less than 10 mph (BASF Corp., 2017; Dow AgroSciences, 2017).

Herbicides such as 2,4-D and dicamba are also susceptible to off-target movement through secondary drift, which includes volatilization. Several environmental factors such as temperature, wind speed, addition of glyphosate, or relative humidity can influence volatility (Behrens and Lueschen, 1979; Bish et al., 2019; Egan and Mortensen, 2012; Sosnoskie et al., 2015). However, two of the most important factors that influence volatility are the vapor pressure and formulation of a herbicide. Both 2,4-D and dicamba have relatively high vapor pressure and are susceptible to volatilization (Shaner, 2014).

Few studies have examined the effects of off-target movement of 2,4-D and dicamba on a variety of garden annual species. Hatterman-Valenti and Mayland (2005) applied sublethal rates of 2,4-D, dicamba, and 2,4-D + dicamba + mecoprop at 5%, 10%, and 20% of the labeled rates on various annual flowers including impatiens (*Impatiens walleriana*), zonal geranium (*Pelargonium ×hortorum*), and african marigold (*Tagetes erecta*) during early flowering stages. Impatiens and zonal geranium were some of the most tolerant species tested, with less than 10% and 16% visual injury, respectively, across all rates and herbicides. These authors also found that sublethal rates of dicamba caused an increase in flowering on impatiens, whereas sublethal rates of 2,4-D did not. However, some annual flower species tested were more sensitive to sublethal rates of 2,4-D and dicamba including floss flower (*Ageratum houstonianum*) and sweet alyssum (*Lobularia maritima*). Another study conducted by Hatterman-Valenti et al. (1995) found that impatiens and zonal geranium were more tolerant to sublethal rates of triclopyr and 2,4-D but that african marigold, petunia, and wax begonia were more sensitive to these herbicide treatments. Reduced flowering was also observed with increasing rates of 2,4-D and triclopyr on petunia and african marigold but not on impatiens (Hatterman-Valenti et al., 1995).

Collectively, these results show that select garden annuals are variable

in their response to herbicide treatments containing 2,4-D or dicamba. However, few studies exist that have investigated the effect of 2,4-D or dicamba combined with glyphosate on garden annuals. Because 2,4-D and dicamba are selective herbicides that only control of broadleaf weeds, adding glyphosate to 2,4-D or dicamba will provide broad spectrum control of broadleaf and grass weeds. Glyphosate will be a common tank-mix component in these 2,4-D-or dicamba-resistant cropping systems. Therefore, the likelihood of drift from a combination of these herbicides will increase. Often, homeowners or commercial greenhouses and nurseries will be located near or around row crop production areas, and therefore drift from these herbicides may affect sensitive plants, including garden annuals. For example, Bradley (2017) reported that in 2017, 40 residential properties, which included garden annuals, trees, and shrubs, were injured by off-target movement of dicamba in Missouri. In addition, 11 commercial gardens were reported to have injury symptoms from dicamba drift in 2017. In June 2018, there were four reported cases of annual flowers experiencing injury from dicamba off-target movement between Arkansas and Missouri (Bradley, 2018). Because 2017 and 2018 were the first years that the dicamba-resistant crop technology was commercially available with an approved herbicide to apply over top of these crops, it is likely that at least some portion of these incidents were a result of off-target movement of dicamba from nearby dicamba-resistant cotton or soybean fields. In the future, if greater adaption of 2,4-D-resistant crops occurs in U.S. agriculture, there is also the potential for an increased number of off-target movement incidents with 2,4-D. Therefore, the objective of this research was to determine the sensitivity of common garden annuals to sublethal rates of 2,4-D and dicamba with and without glyphosate.

Materials and methods

Eight common garden annual plant species; ‘Dazzler’ impatiens, ‘Pinto’ zonal geranium, ‘Hurrah’ petunia, ‘Bonanza’ french marigold (*Tagetes patula*), ‘Prelude’ wax begonia (*Begonia ×semperflorens-cultorum*), ‘Titan’

madagascar periwinkle (*Catharanthus roseus*), ‘Double Zahara’ zinnia (*Zinnia marylandica*), and ‘Wizard’ coleus (*Solenostemon scutellarioides*); were donated from Trinklein Brothers Greenhouses (Jefferson City, MO) in 50-count plug trays in early Mar. 2017 and 2018 to the University of Missouri, Division of Plant Sciences (Columbia). Plugs were then transplanted in a 3-inch pot on 12 Apr. 2017 and 11 Apr. 2018. Potting soil contained a commercial potting medium composed of 70% Canadian sphagnum peatmoss, 15% vermiculite, and 15% perlite (Premier Tech Horticulture, Quakertown, PA). Garden annual plants in the 3-inch pots were grown and maintained daily in a heated high tunnel where natural lighting was provided. Light in the high tunnel was not monitored; however, temperatures in the high tunnel were set for 75 and 65 °F days and nights, respectively. Annual flowers received a continuous liquid feed solution of 175 ppm nitrogen from a 21N-2.2P-16.6K fertilizer (Peters Excel Multi-Purpose Fertilizer 21-5-20; ICL Specialty Fertilizers, Summerville, SC).

On 23 May 2017 and 29 May 2018, all species were removed from the heated high tunnel and treated with 1/10×, 1/100×, and 1/300× of the manufacture’s full labeled rate (1× rate) of 2,4-D choline (Enlist One; Dow AgroSciences, Indianapolis, IN), 2,4-D choline plus glyphosate (Enlist Duo, Dow AgroSciences), dicamba diglycolamine (DGA) salt (Xtendimax with VaporGrip; Monsanto, St. Louis, MO), and dicamba DGA plus glyphosate (Roundup Powermax, Monsanto). At the time of treatment, all species were ≈10 cm in height with three to four flowers present, apart from no flowers on coleus. The full labeled rates that were used to calculate the fraction rates for 2,4-D, 2,4-D plus glyphosate, dicamba, and dicamba plus glyphosate were 1.0 lb/acre, 1.0 lb/acre plus 1.0 lb/acre, 0.5 lb/acre, and 0.5 lb/acre plus 1.0 lb/acre, respectively. A nontreated control of each flower species was also included for comparison. All treatments were applied with a carbon dioxide-pressurized backpack sprayer equipped with flat spray nozzles (TeeJet 8002 XR; Spraying Systems, Wheaton, IL) at 15 gal/acre and 19 psi. Applications were made

with a 10-ft boom spraying ≈ 16 inches directly over the top of each species. Flat fan nozzles were used to simulate the fine droplets that are most likely to drift from a nearby field application and move off-site to a sensitive species.

One day after treatment, all flower species were transplanted into raised beds (1 ft tall and 3 ft wide) at the University of Missouri Bradford Research Center, Columbia (lat. 38.8929°N, long. 92.2010°W) with a 1.25-mil white on black plastic mulch layer (FilmTech Corp, Allentown, PA) at row spacings of 6 and 9 inches in 2017 and 2018, respectively. Irrigation was provided via 10-mil sub drip irrigation tape with 4-inch spacing that emitted water at a rate of 1 gal/h (Chapin; Jain Irrigation, Watertown, NY) on a biweekly basis until the end of the experiment, ≈ 56 d after treatment (DAT). The soil at this location was a Mexico silt loam (finene, smectic, mesic Aeric Vertic Epiaqualfs) with 2.4% organic matter and a pH of 6.0. Soil was supplemented with 90 lb/acre of urea fertilizer (Bruce Oakley, North Little Rock, AK) containing an analysis of 46N-0P-0K ≈ 2 weeks before transplant. No herbicides were applied to the soil, to ensure that symptoms observed were from the foliar-applied treatments. Hand weeding and cultivation were used to eliminate weed pressure. The experimental design was a randomized complete block design in a split-plot arrangement with five single-plant replications. Individual species were whole plots while subplots consisted of herbicide treatments.

All garden annuals were evaluated for overall injury on a scale from 0% to 100%, where 0% = no injury, 1% to 25% = slight leaf malformation, cupping, and epinasty, 26% to 50% = reduced growth, significant epinasty, and slight necrosis or chlorosis, 51% to 75% = severe necrosis, stem swelling, chlorosis, and epinasty, 76% to 99% death of main stem, severe plant stunting, and necrosis, and 100% = complete plant death. Visible injury assessments were taken 28 and 56 DAT and included an overall evaluation of chlorosis and necrosis of plant tissue as well as leaf cupping, strapping, and overall plant epinasty resulting from herbicide treatments. Plant height measurements were recorded in cm

28 and 56 DAT by measuring individual plant heights from the soil surface to the top of living plant tissue. Flower production was assessed by counting the number of open, developed flowers, with ray florets perpendicular to the pedicel per plant 28 DAT. Because coleus is grown primarily for foliage display, flower production for this species was not collected and was not included in the analysis. Additionally, above-ground dry weight samples were harvested 56 DAT by clipping at the soil surface, drying in a forced air oven at 120 °F for 36 h, and then weighing.

All data were analyzed in SAS (version 9.4; SAS Institute, Cary, NC) using PROC GLIMMIX. Least square means were separated using Fisher's least significant difference test at $P \leq 0.05$. Herbicide, rate, and garden annuals and their interactions were considered fixed effects, and year and replication nested within year were considered to be random effects. Years were classified as random effects so conclusions about species or treatments could be made over a wide range of environments (Blouin et al., 2011; Carmer et al., 1989). One-, two-, and three-way interactions were tested using type III tests of fixed effects. Because each garden annual plant species are distinctly different from one another, height, flower production, and dry weight were analyzed by species. Rate and herbicide were combined into a single variable to directly compare injured plants to the nontreated control for height, flower production, and dry weight measurements.

Results and discussion

VISIBLE INJURY 28 DAT. Visual injury symptoms from 2,4-D or dicamba with or without glyphosate included leaf cupping, strapping, epinasty of stems and petioles, callusing and swelling of stem tissue and flowers, stem cracking, necrosis, chlorosis, and plant death. Such symptoms are consistent with those reported by Hatterman-Valenti and Mayland (2005) on various annual flower species. All one-, two-, and three-way interactions of fixed effects were significant for injury ratings 28 DAT ($P < 0.0001$). When 2,4-D plus glyphosate was applied at the 1/10 $\times$ rate, wax begonia, coleus, zonal geranium,

petunia, and zinnia resulted in greater than 50% injury. When dicamba plus glyphosate was applied at the 1/10 $\times$ rate, coleus, petunia, and zinnia resulted in greater than 50% injury. (Table 1). When averaged across all plant species, glyphosate in combination with 2,4-D at the 1/10 $\times$ rate resulted in significantly greater injury (51%) than dicamba plus glyphosate at the 1/10 $\times$ rate [43% (data not shown)]. Greater injury occurred in response to the 1/10 $\times$ rate of 2,4-D plus glyphosate compared with the 1/10 $\times$ rate of 2,4-D alone in all species except french marigold. For example, petunia showed 2% and 65% injury from the 1/10 $\times$ rates of 2,4-D and 2,4-D plus glyphosate, respectively (Table 1). Similarly, greater injury was observed in response to dicamba plus glyphosate at the 1/10 $\times$ rate compared with dicamba alone at the 1/10 $\times$ rate in all species except wax begonia and impatiens (Table 1). With the exceptions noted above, these results indicate that treatments containing glyphosate in combination with dicamba or 2,4-D at the 1/10 $\times$ rates result in greater injury than dicamba or 2,4-D alone. Similar results from Mohseni-Moghadam et al. (2015) indicate that combinations of 2,4-D or dicamba with glyphosate caused greater injury on grape (*Vitis vinifera*) compared with either of these herbicides alone. Hatterman-Valenti and Mayland (2005) reported that a combination of 2,4-D plus dicamba plus mecoprop resulted in 17% injury to salvia (*Salvia splendens*) while dicamba and 2,4-D applied alone resulted in 7% and 10% injury, respectively. Synergistic effects of 2,4-D plus glyphosate and dicamba plus glyphosate on weed control have also been shown (Craigmyle et al., 2013; Flint and Barrett, 1989; Johnson et al., 2010).

The 1/100 $\times$ rate of dicamba plus glyphosate resulted in 1% to 39% injury on the eight species evaluated in these experiments, whereas the 1/100 $\times$ rate of 2,4-D plus glyphosate resulted in 0% to 7% injury (Table 1). Across all garden annuals, dicamba combined with glyphosate caused significantly greater injury (13%) in comparison with 2,4-D plus glyphosate at the 1/100 $\times$ rate [4% (data not shown)]. Species exhibited 0% to 3% injury in response to the 1/300 $\times$ rate of all treatments (Table 1).

Table 1. Visible injury of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 28 d after treatment.

		Garden annuals							
		Wax begonia	Coleus	Zonal geranium	Impatiens	French marigold	Petunia	Madagascar periwinkle	Zinnia
Treatment	Rate ^z	----- Visual injury (%) ^y -----							
2,4-D	1/300×	1 rs ^x	0 s	0 s	0 rs	0 s	0 s	1 rs	0 rs
2,4-D	1/100×	1 rs	2 q-s	1 rs	1 rs	3 q-s	0 s	0 s	5 p-s
2,4-D	1/10×	18 h-o	26 g-k	42 ef	15 i-q	28 gh	2 q-s	5 p-s	26 g-j
2,4-D + glyphosate	1/300×	0 rs	1 rs	0 s	0 s	2 q-s	0 rs	0 rs	2 q-s
2,4-D + glyphosate	1/100×	1 rs	7 o-s	6 os	3 q-s	7 o-s	0 rs	4 p-s	7 o-s
2,4-D + glyphosate	1/10×	60 cd	78 a	65 bc	28 gh	39 fg	65 bc	24 h-k	51 d-f
Dicamba	1/300×	0 rs	2 q-s	1 rs	0 rs	0 s	0 s	0 s	0 rs
Dicamba	1/100×	3 q-s	11 l-s	2 q-s	3 q-s	1	0 s	2 rs	8 n-s
Dicamba	1/10×	13 k-r	27 g-i	13 k-r	17 h-p	9 m-s	5 p-s	4 p-s	21 h-m
Dicamba + glyphosate	1/300×	1 rs	3 q-s	0 s	1 rs	1 rs	0 s	1 rs	3 q-s
Dicamba + glyphosate	1/100×	1 rs	39 fg	9 m-s	9 m-s	5 p-s	27 g-i	5 p-s	13 j-r
Dicamba + glyphosate	1/10×	18 h-o	79 a	50 d-f	19 h-n	24 h-l	74 ab	25 g-k	53 c-e
LSD(0.05) ^w		13							

^zRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre); 1 lb/acre = 1.1209 kg·ha⁻¹.

^yVisual injury is rated on a scale from 0% to 100%, where 0% = no injury; 1% to 25% = slight leaf malformation, cupping, and epinasty; 26% to 50% = reduced growth, significant epinasty, and slight necrosis or chlorosis; 51% to 75% = severe necrosis, stem swelling, chlorosis, and epinasty; 76% to 99% death of main stem, severe plant stunting and necrosis; and 100% = complete plant death.

^xMeans within table followed by the same letter are not significantly different according to Fisher's least significant difference (LSD) test ($P < 0.05$).

^wGarden annuals × rate × herbicide interaction $P < 0.001$.

On the basis of the 1/10× rates of 2,4-D and dicamba, zonal geranium and french marigold had a greater sensitivity to 2,4-D. Hatterman-Valenti and Mayland (2005) found african marigold to be more sensitive to 2,4-D than dicamba. Coleus and petunia exhibited increased sensitivity to 1/100× treatments of dicamba plus glyphosate compared with 2,4-D plus glyphosate. Coleus was the most injured species [22% injury (data not shown)] to all treatments of 2,4-D and dicamba with or without glyphosate while madagascar periwinkle, impatiens, french marigold, and wax begonia were the least injured [6% to 10% (data not shown)]. Hatterman-Valenti et al. (1995) reported that impatiens and madagascar periwinkle had a low susceptibility to reduced rates of various synthetic auxin herbicide treatments.

VISIBLE INJURY 56 DAT. All interactions of herbicide, rate, and garden annuals were significant for injury ratings 56 DAT ($P < 0.0001$). Injury from 1/300× rates of all treatments ranged from 0% to 3% across the plant species, similarly to 28 DAT (Tables 1 and 2). However, Hatterman-Valenti et al. (1995) reported that 2,4-D applied at 1 g·ha⁻¹ (≈1/1000×) resulted in injury ranging from 10%

to 18% on french marigold, petunia, wax begonia, impatiens, zonal geranium, and madagascar periwinkle 8 weeks after treatment. Results from Hatterman-Valenti et al. (1995) may have differed from those found here due to the differences in herbicide formulations and the growth stage of the species in the studies. Additionally, Hatterman-Valenti et al. (1995) likely observed greater injury because plants were kept in the greenhouse following treatment. Less than 3% injury was observed in response to 1/100× treatments of 2,4-D and 2,4-D plus glyphosate. However, 0% to 32% injury was observed with 1/100× treatments of dicamba and dicamba plus glyphosate across all flower species (Table 2). Similar to the responses observed 28 DAT, 1/100× treatments of dicamba plus glyphosate resulted in greater injury than 2,4-D plus glyphosate.

By 56 DAT, several species had recovered from the initial injury that occurred 28 DAT. madagascar periwinkle exhibited 24% and 25% visual injury 28 DAT in response to 1/10× treatments of 2,4-D plus glyphosate and dicamba plus glyphosate, respectively. However, by 56 DAT madagascar periwinkle injury had declined to 8% for both treatments (Tables 1

and 2). Similarly, dicamba and 2,4-D applied to zinnia at the 1/10× rate resulted in 21% and 26% visual injury 28 DAT, but by 56 DAT only 6% and 5% visual injury was observed, respectively (Tables 1 and 2). Petunia, impatiens, and wax begonia expressed similar levels of injury between 28 and 56 DAT (Tables 1 and 2). Petunia injury increased by 26% and 12% from 28 DAT to 56 DAT in response to 1/10× treatments of 2,4-D plus glyphosate and dicamba plus glyphosate, respectively. This in large part was due to the increase in tissue death and overall necrosis that was observed. Another study found that rose (*Rosa dilecta*) expressed similar levels of injury from 30 to 60 DAT with applications of 1/10× and 1/3× rates of 2,4-D plus glyphosate (Al-Khatib et al., 1992b). Overall, differences that were observed 28 DAT were also present 56 DAT. For example, petunia had significantly greater injury caused by 2,4-D or dicamba plus glyphosate compared with 2,4-D or dicamba alone at the 1/10× rates both 28 and 56 DAT. Additionally, zonal geranium was found to have greater injury caused by 2,4-D compared with dicamba at the 1/10× rate both 28 and 56 DAT (Tables 1 and 2).

Table 2. Visible injury of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 56 d after treatment.

Treatment	Rate ^a	Garden annuals							
		Wax begonia	Coleus	Zonal geranium	Impatiens	French marigold	Petunia	Madagascar periwinkle	Zinnia
		Visual injury (%) ^y							
2,4-D	1/300×	1 m ^x	0 m	0 m	0 m	0 m	0 m	0 m	0 m
2,4-D	1/100×	2 m	0 m	0 m	0 m	1 m	0 m	0 m	0 m
2,4-D	1/10×	8 k-m	11 j-m	43 ef	10 j-m	22 g-j	3 m	2 m	5 k-m
2,4-D + glyphosate	1/300×	0 m	1 m	0 m	0 m	0 m	0 m	0 m	0 m
2,4-D + glyphosate	1/100×	1 m	2 m	1 m	0 m	0 m	0 m	0 m	2 m
2,4-D + glyphosate	1/10×	60 cd	73 b	64 bc	32 fg	27 gh	86 a	8 k-m	50 de
Dicamba	1/300×	0 m	3 m	0 m	0 m	0 m	0 m	0 m	0 m
Dicamba	1/100×	3 m	12 i-m	0 m	0 m	0 m	0 m	1 m	1 m
Dicamba	1/10×	11 j-m	34 fg	5 l-m	16 h-k	6 k-m	0 m	2 m	6 k-m
Dicamba + glyphosate	1/300×	0 m	0 m	0 m	0 m	1 m	0 m	0 m	0 m
Dicamba + glyphosate	1/100×	0 m	25 g-i	2 m	2 m	4 m	32 fg	2 m	7 k-m
Dicamba + glyphosate	1/10×	17 h-k	76 ab	43 ef	17 h-k	24 g-i	86 a	8 k-m	43 ef
LSD(0.05) ^w		12							

^aRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre); 1 lb/acre = 1.1209 kg·ha⁻¹.

^yVisual injury is rated on a scale from 0% to 100%, where 0% = no injury; 1% to 25% = slight leaf malformation, cupping, and epinasty; 26% to 50% = reduced growth, significant epinasty, and slight necrosis or chlorosis; 51% to 75% = severe necrosis, stem swelling, chlorosis, and epinasty; 76% to 99% death of main stem, severe plant stunting and necrosis; and 100% = complete plant death.

^xMeans within table followed by the same letter are not significantly different according to Fisher's least significant difference (LSD) test ($P < 0.05$).

^wGarden annuals × rate × herbicide interaction $P < 0.001$.

PLANT HEIGHT. There was a significant species by treatment interaction for all species on plant height 28 DAT ($P < 0.0001$). 2,4-D plus glyphosate applied at the 1/10× rate resulted in reduced plant heights compared with the non-treated control for all species. Dicamba plus glyphosate applied at the 1/10× rate reduced plant heights of all species except wax begonia and impatiens (Table 3). Wax begonia, zonal geranium, and french marigold were the only species to have reductions in plant heights from 1/10× treatments of 2,4-D. However, in previous research the height of sweet cherry (*Prunus avium*) trees were not reduced from 1/10× treatments of 2,4-D (Al-Khatib et al., 1992a). This may have been due to the different formulations of 2,4-D used or because of the time after treatments that height measurements were recorded. Zinnia was the only species to express reduced plant height from dicamba applied at the 1/10× rate. Solomon and Bradley (2014) found that 1/20× rates of dicamba caused significant reductions in soybean height compared with 2,4-D applied at the same rate, suggesting that soybean are more sensitive to dicamba

compared with 2,4-D. Coleus, french marigold, and petunia were the only species that had reductions in plant height resulting from 1/100× rates of 2,4-D plus glyphosate or dicamba plus glyphosate.

When plants heights were recorded again 56 DAT, there was a significant treatment by species interaction for all species except impatiens ($P < 0.0001$). The 1/10× rate of 2,4-D plus glyphosate resulted in significant reductions in plant height, ranging from 6 to 28 cm less than the nontreated across all species, except impatiens (Table 4). Dicamba combined with glyphosate at the 1/10× rate caused significant reduction in plant height in all species except wax begonia and impatiens. Dicamba at the 1/10× rate only significantly reduced plant height in coleus. When 2,4-D was applied at the 1/10× rate coleus, zonal geranium, and french marigold resulted in significantly reduced plant heights of 29, 18, and 20 cm, respectively, compared with their controls (Table 4). Plant heights for zonal geranium and french marigold showed similar differences 28 and 56 DAT (Tables 3 and 4), indicating that these species may have a greater sensitivity toward 2,4-D.

However, Culpepper et al. (2018) showed watermelon (*Citrullus lanatus*) to have greater reductions of vine length with treatments of dicamba compared with 2,4-D, indicating that plant species can differ in their overall sensitivity or reduction in growth to 2,4-D or dicamba. Except for coleus, no other treatments applied at the 1/100× or 1/300× rate resulted in significant reductions in plant height 56 DAT (Table 4). Coleus height was 20 and 8 cm less compared with the nontreated control (39 cm) for 1/100× and 1/300× treatments of dicamba plus glyphosate, respectively, 56 DAT (Table 4). Similarly, Culpepper et al. (2018) demonstrated that watermelon vine length was reduced by as much 39% when dicamba was applied at the 1/250× rate 20 d after planting. Injury evaluations 56 DAT show that coleus was injured most, ranging from 25% to 76% injury, from treatments of dicamba plus glyphosate at the 1/10× and 1/100× rates (Table 2). Even though significant damage was not observed on coleus 56 DAT from the 1/300× rate of dicamba plus glyphosate, coleus plant height was significantly reduced compared with the nontreated. Previous research by Solomon and Bradley

Table 3. Height of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 28 d after treatment.

Treatment	Rate ^z	Garden annuals							
		Wax begonia	Coleus	Zonal geranium	Impatiens	French marigold	Petunia	Madagascar periwinkle	Zinnia
		Visual injury (%) ^y							
Non-treated	—	14 ab ^x	16 ab	21 ab	15 a-c	19 a	20 a	19 a	18 ab
2,4-D	1/300×	15 a	18 a	23 a	15 ab	19 a	20 ab	18 a	19 a
2,4-D	1/100×	14 ab	18 a	22 a	16 ab	17 ab	19 a-c	18 a	18 ab
2,4-D	1/10×	10 c	12 b-d	14 de	14 a-d	15 bc	19 a-c	18 a	18 ab
2,4-D + glyphosate	1/300×	13 ab	17 a	22 a	16 ab	18 a	19 a-c	20 a	18 ab
2,4-D + glyphosate	1/100×	13 ab	17 a	22 a	16 ab	18 a	18 bc	19 a	17 a-c
2,4-D + glyphosate	1/10×	5 d	6 e	12 e	13 d	12 d	10 e	13 b	9 d
Dicamba	1/300×	14 ab	19 a	21 ab	14 a-d	17 ab	19 a-c	19 a	17 a-c
Dicamba	1/100×	14 ab	15 a-c	21 ab	15 ab	17 ab	18 c	18 a	16 bc
Dicamba	1/10×	13 ab	16 a	20 a-c	15 ab	17 ab	18 a-c	18 a	14 c
Dicamba + glyphosate	1/300×	14 ab	16 ab	22 a	17 a	19 a	18 a-c	18 a	18 ab
Dicamba + glyphosate	1/100×	14 ab	11 cd	18 bc	14 b-d	15 bc	14 d	18 a	15 bc
Dicamba + glyphosate	1/10×	12 bc	8 de	16 cd	13 cd	13 cd	10 e	15 b	10 d
<i>P</i> value ^w		<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01

^zRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre); 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 cm = 0.3937 inch.

^xMeans within the same column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P < 0.05$).

^wGarden annuals × treatment interaction $P < 0.001$.

(2014) showed that soybean plant heights were generally correlated to injury assessments after treatment with a variety of synthetic auxin herbicides. Similar results occurred in these experiments when the heights of garden annuals were measured 28 and 56 DAT.

FLOWER PRODUCTION. In this study, the highest herbicide rates decreased flower production compared with the nontreated controls (Table 5). Hatterman-Valenti et al. (1995) reported a similar inverse relationship between herbicide rate and flower number for petunia and french marigold. The number of flowers per plant was significantly reduced by 2,4-D plus glyphosate and dicamba plus glyphosate treatments at the 1/10× rate for all species (Table 5).

Across all annuals, the 1/100× rate of 2,4-D did not cause significantly reduced flower production compared with their non-treated controls. Dicamba at 1/100× rate significantly reduced flower production on zonal geranium and zinnia (Table 5). Madagascar periwinkle was the only garden annual species to have a significantly reduced flower count resulting from the 1/100× rate of 2,4-D plus glyphosate. However, zonal geranium, petunia, madagascar

periwinkle, and zinnia showed significant reductions of 4 to 11 flowers per plant compared with the nontreated control from 1/100× rates of dicamba plus glyphosate (Table 5). Collectively, these results indicate that significant flower loss was more likely to occur with 1/100× treatments of dicamba plus glyphosate in comparison with 2,4-D plus glyphosate.

There was not a significant loss in flower production in response to 1/300× rates of herbicide treatments for any of the species tested (Table 5). Although some low dose herbicide treatments resulted in higher flower counts, they were not different from the control. Hatterman-Valenti and Mayland (2005) showed that sublethal rates of 2,4-D and dicamba reduced flowering of floss flower and sweet alyssum more than in dahlia (*Dahlia hortensis*), zonal geranium, impatiens, african marigold, salvia, and snapdragon (*Antirrhinum majus*). In addition, Kruger et al. (2012) reported that dicamba rates as low as 2.7 g·ha⁻¹ ($\approx 1/200\times$) caused up to a 10% flower loss in tomato (*Solanum lycopersicum*). Collectively, the results from our research and others indicates that growers of annual garden species may use flower production as a means of measuring

the severity of off-target movement of 2,4-D or dicamba with or without glyphosate.

DRY WEIGHT. There was a significant species by treatment interaction for plant dry weight 56 DAT for all species except wax begonia ($P < 0.0001$). Across the seven species in Table 6, 1/10× treatments of 2,4-D plus glyphosate caused significant dry weight reduction compared with the non-treated control for each species. Dicamba plus glyphosate at the 1/10× rate caused reductions in plant dry weight on all species except wax begonia and impatiens (Table 6). These results are consistent with the previous measurements of injury, height, and flower production, and confirm that combinations of 2,4-D plus glyphosate or dicamba plus glyphosate results in the greatest injury to the garden annuals evaluated in this research.

Coleus, zonal geranium, french marigold, and madagascar periwinkle had reduced dry weight from 2,4-D applied at the 1/10× rate, whereas coleus, madagascar periwinkle, and zinnia were the only species to have reduced dry weight as a result of 1/10× rates of dicamba (Table 6). Petunia did not have significant

Table 4. Height of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 56 d after treatment.

Treatment	Rate ^v	Garden annuals ^z						
		Wax begonia	Coleus	Zonal geranium	French marigold	Petunia	Madagascar periwinkle	Zinnia
		Visual injury (%) ^x						
Non-treated	—	20 a ^w	39 a	27 ab	24 a	26 a	35 a	29 a
2,4-D	1/300×	21 a	36 ab	27 ab	25 a	26 a	35 a	29 a
2,4-D	1/100×	21 a	35 ab	28 a	24 a	24 a	34 a	26 a
2,4-D	1/10×	17 a	29 bc	18 de	20 b-d	25 a	33 ab	30 a
2,4-D + glyphosate	1/300×	19 a	35 ab	28 ab	23 ab	25 a	34 ab	30 a
2,4-D + glyphosate	1/100×	20 a	33 ab	28 ab	24 a	25 a	34 a	26 a
2,4-D + glyphosate	1/10×	7 b	11 e	15 e	18 d	12 b	29 c	14 b
Dicamba	1/300×	20 a	35 ab	27 ab	23 a-c	25 a	33 ab	27 a
Dicamba	1/100×	21 a	29 b	28 ab	22 a-d	24 a	33 ab	28 a
Dicamba	1/10×	18 a	22 cd	28 ab	22 a-d	26 a	33 ab	24 a
Dicamba + glyphosate	1/300×	20 a	31 b	27 ab	22 a-d	26 a	33 ab	29 a
Dicamba + glyphosate	1/100×	21 a	19 d	24 bc	22 a-d	25 a	33 ab	24 a
Dicamba + glyphosate	1/10×	19 a	9 e	21 cd	19 cd	17 b	31 b	18 b
P value ^v		<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01

^zData for impatiens are not presented; height differences were not observed 56 DAT ($P > 0.05$).

^vRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre) = 1.1209 kg·ha⁻¹.

^x1 cm = 0.3937 inch.

^wMeans within the same column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P < 0.05$).

^vGarden annuals × treatment interaction $P < 0.001$.

reductions in dry weight as a result of 2,4-D or dicamba treatments applied alone, confirming that this species has a high tolerance to sublethal rates of 2,4-D and dicamba. French marigold and zonal geranium did not experience significant reductions in dry weight as a result of 1/10× treatments of dicamba, but dry weight was reduced for the equivalent treatments of 2,4-D (Table 6). A similar trend was observed with visual injury 28 and 56 DAT (Tables 1 and 2), thus confirming zonal geranium and french marigold have a higher sensitivity to 2,4-D.

Madagascar periwinkle was the only species to have significantly reduced dry weight in response to the 1/100× rate of 2,4-D, whereas coleus was the only species to have significantly reduced dry weight in response to dicamba applied at the 1/100× rate (Table 6). When glyphosate was added to the 1/100× rates of dicamba and 2,4-D, significant dry weight reductions occurred on coleus and petunia. None of the species, except coleus, had reduced dry weight resulting from the 1/300× rates of any herbicide treatment. Coleus dry weight was reduced to 22 and 20 g from 1/300× rates of 2,4-D plus

glyphosate and dicamba plus glyphosate, respectively, compared with the nontreated control dry weight of 37 g (Table 6). Additionally, the 1/300× rate of 2,4-D applied to zonal geranium, and the 1/100× rate of dicamba applied to impatiens were the only treatments that resulted in dry weights of 10 and 9 g greater than the nontreated control, respectively (Table 6). These results indicate that 2,4-D or dicamba at low concentrations may cause an increase in zonal geranium and impatiens plant dry weight. This result may be explained by a phenomenon known as hormesis, which states that inhibitors can become growth stimulants at low doses (Mattson, 2008). Hatterman-Valenti et al. (1995) found that 2,4-D applied at 25 g·ha⁻¹ (≈1/50×) resulted in a 4% dry weight gain on average for impatiens, french marigold, and petunia. Hemphill and Montgomery (1981) also reported that 2.1 g·ha⁻¹ 2,4-D (≈1/500×) resulted in 136% pepper (*Capsicum frutescens*) yield of the nontreated. The authors from this study concluded this result was likely due to increased branching and flowering on pepper.

The results of this research indicate that garden annuals respond

differently from one another to treatments containing 2,4-D or dicamba with or without glyphosate. Coleus was found to be the most sensitive species in this study, whereas wax begonia, impatiens, french marigold, and madagascar periwinkle had the least sensitivity to the herbicide treatments evaluated. If homeowners or commercial growers are located near areas where 2,4-D or dicamba resistant crops are grown, coleus annual garden species will likely show greater signs of visual injury if off-target movement occurs. Conversely, madagascar periwinkle or wax begonia appear to be better suited for areas where 2,4-D or dicamba resistant crops are grown because of their reduced sensitivity to sublethal rates of 2,4-D or dicamba with or without glyphosate. French marigold and zonal geranium had greater sensitivity to treatments containing 2,4-D compared with dicamba. On the other hand, coleus and zinnia had greater sensitivity to treatments containing dicamba compared with 2,4-D. Therefore, homeowners or commercial growers of garden annuals such as french marigold or zonal geranium and coleus or zinnia that are located in areas where 2,4-D or dicamba

Table 5. Flower production of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 28 d after treatment.

		Garden annuals ^z						
		Wax begonia	Zonal geranium	Impatiens	French marigold	Petunia	Madagascar periwinkle	Zinnia
Treatment	Rate ^y	-----Flowers (no./plant)-----						
Non-treated	—	11 ab ^x	6 ab	9 a	11 a-c	15 a-c	11 ab	7 a-c
2,4-D	1/300×	13 a	6 ab	7 a	12 ab	17 a	11 a-d	7 a-c
2,4-D	1/100×	12 ab	4 bc	8 a	10 bc	16 ab	10 b-d	8 ab
2,4-D	1/10×	5 cd	0 d	6 a-d	6 de	14 a-c	5 ef	3 ef
2,4-D + glyphosate	1/300×	11 ab	8 a	6 a-c	11 a-c	14 a-c	14 a	7 a-c
2,4-D + glyphosate	1/100×	10 ab	4 bc	7 ab	11 a-c	12 c	8 c-e	6 cd
2,4-D + glyphosate	1/10×	1 d	0 d	2 d	3 e	0 e	3 f	1 f
Dicamba	1/300×	11 ab	6 ab	7 a-c	10 bc	16 ab	10 b-d	6 b-d
Dicamba	1/100×	12 a	2 cd	7 ab	13 ab	12 c	11 a-c	4 de
Dicamba	1/10×	8 bc	1 cd	3 cd	11 bc	14 a-c	5 ef	3 e
Dicamba + glyphosate	1/300×	12 ab	6 ab	8 a	14 a	13 bc	10 b-d	9 a
Dicamba + glyphosate	1/100×	10 ab	1 cd	8 a	8 cd	4 d	7 de	2 ef
Dicamba + glyphosate	1/10×	6 c	0 d	3 b-d	5 e	0 e	3 f	1 f
P value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

^zColeus flower production was not recorded because this species is primarily grown for foliage display.

^yRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre); 1 lb/acre = 1.1209 kg·ha⁻¹.

^xMeans within the same column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P < 0.05$).

resistant crops are produced will likely see greater and more frequent injury from 2,4-D or dicamba, respectively. For wax begonia, impatiens, petunia, and madagascar periwinkle, there was not a clear trend toward a greater sensitivity to 2,4-D or dicamba. However, these species may still experience injury symptoms from high sublethal rates of these herbicides coming from agricultural fields. Petunia expressed the least sensitivity toward all rates of 2,4-D or dicamba applied alone. However, petunia had the greatest levels of injury when glyphosate was combined with 2,4-D or dicamba at the 1/10× rate, indicating that petunia is highly sensitive to treatments of glyphosate when combined with either 2,4-D and dicamba. The results of this research indicate that homeowners or commercial growers would likely not see injury to petunia from off-target movement of dicamba or 2,4-D applied alone. However, because glyphosate will commonly be used as a tank-mix partner in dicamba and 2,4-D resistant crops to achieve broad spectrum weed control, injury would likely be apparent on petunia in the form of necrosis, reduced plant height, and reduced flowering only if a severe drift event occurred.

When glyphosate was applied with dicamba or 2,4-D at 1/10× rates, visual injury along with reductions in plant height, dry weight, and flower production were the greatest for coleus, zonal geranium, french marigold, petunia, madagascar periwinkle, and zinnia. Less injury occurred when 1/10× rates of 2,4-D or dicamba were applied without glyphosate, and lower levels of injury and growth reduction were observed in response to 1/100 and 1/300× rates of 2,4-D and dicamba, with or without glyphosate compared with 1/10× rates.

Egan et al. (2014) reported that sublethal rates of 2,4-D or dicamba corresponding to as much as a 1/10× use rate is a rare off-target movement occurrence but that rates corresponding to 1/100× or 1/300× are more likely to occur in most field settings. In this research, garden annuals exhibited low sensitivity to 1/100× or 1/300× rates of 2,4-D and dicamba with or without glyphosate, with the exception of coleus. Apart from coleus, no species in this study had significant reductions in growth or dry weight from the 1/300× rates of 2,4-D or dicamba plus glyphosate. Compared with previous studies that have examined the effects of sublethal

rates of 2,4-D or dicamba on soybean, snap bean (*Phaseolus vulgaris*), grape, cotton, tomato, and watermelon (Al-Khatib and Peterson, 1999; Colquhoun et al., 2014; Culpepper et al., 2018; Egan et al., 2014; Kruger et al., 2012; Marple et al., 2007; Mohseni-Moghadam et al., 2015; Solomon and Bradley, 2014), all garden annuals in this study except for coleus appear to be less susceptible to sublethal rates of 2,4-D or dicamba with or without glyphosate. However, results from this study may have differed if plants were established in the ground before herbicide treatment. Regardless, if homeowners and/or producers of annual garden species are located in areas where 2,4-D or dicamba resistant crops are grown, one potential solution may be to temporarily cover up or shield sensitive species when herbicide applications are being made. However, it is important to note that dicamba and 2,4-D can also move off-target through volatility. Results from both Bish et al. (2019) and Sosnoskie et al. (2015) illustrate that even the new formulations of dicamba and 2,4-D can be detected in the air following application. Although air concentrations of these new formulations may remain low, this type of secondary drift still has the

Table 6. Dry weight of garden annuals in response to sublethal rates of 2,4-D and dicamba with or without glyphosate 56 d after treatment.

Treatment	Rate ^y	Garden annuals ^z						
		Coleus	Zonal geranium	Impatiens	French marigold	Petunia	Madagascar periwinkle	Zinnia
		Dry wt (g) ^x						
Non-treated	—	37 a ^w	25 bc	17 b-d	34 ab	46 a	40 ab	56 ab
2,4-D	1/300×	36 a	35 a	20 a-d	33 ab	44 ab	37 a-c	49 a-c
2,4-D	1/100×	27 ab	30 a-c	20 a-d	30 a-c	42 ab	31 c	51 a-c
2,4-D	1/10×	20 bc	12 d	14 c-e	22 c-e	34 ab	31 c	48 a-c
2,4-D + glyphosate	1/300×	22 bc	30 a-c	21 a-d	29 a-c	38 ab	41 a	51 a-c
2,4-D + glyphosate	1/100×	20 bc	31 a-c	25 ab	28 a-d	32 b	34 a-c	40 bc
2,4-D + glyphosate	1/10×	2 d	8 d	8 e	18 de	4 c	22 d	8 d
Dicamba	1/300×	29 ab	26 bc	14 c-e	33 ab	48 a	35 a-c	58 a
Dicamba	1/100×	17 bc	33 ab	26 a	31 a-c	39 ab	36 a-c	45 a-c
Dicamba	1/10×	10 cd	30 a-c	15 c-e	28 a-d	37 ab	32 c	38 c
Dicamba + glyphosate	1/300×	20 bc	32 ab	23 a-c	36 a	40 ab	35 a-c	52 a-c
Dicamba + glyphosate	1/100×	9 cd	24 c	17 b-d	24 b-d	29 b	33 bc	43 a-c
Dicamba + glyphosate	1/10×	2 d	11 d	13 de	14 e	2 c	22 d	11 d
P value ^v		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

^zData for wax begonia are not presented; dry weight differences were not observed ($P > 0.05$).

^yRates of herbicides are presented in the fraction of 1× rate (1× rate of 2,4-D = 1.0 lb/acre, 1× rate of dicamba = 0.5 lb/acre, 1× rate of glyphosate = 1.0 lb/acre) = 1.1209 kg·ha⁻¹.

^x1 g = 0.0353 oz.

^wMeans within the same column followed by the same letter are not significantly different according to Fisher's least significant difference test ($P < 0.05$).

^vGarden annuals × treatment interaction $P < 0.001$.

potential to injure sensitive garden annual plant species. Because these garden annuals are short-lived and are grown for their aesthetic value, it is likely that even low levels of visible injury would not be tolerated by homeowners or commercial retailers.

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