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Source: Weed Technology, 35(3) : 357-362

Published By: Weed Science Society of America

URL: https://doi.org/10.1017/wet.2020.129

Weed Technology

www.cambridge.org/wet

Research Article

Cite this article: Hand LC, Vance JC, Randell TM, Shugart J, Gray T, Luo X, Culpepper AS (2021) Effects of low-dose applications of 2,4-D and dicamba on cucumber and cantaloupe. Weed Technol. **35:** 357–362. doi: 10.1017/wet.2020.129

Received: 29 July 2020
Revised: 1 October 2020
Accepted: 3 November 2020
First published online: 9 November 2020

Associate Editor:
Darren Robinson, University of Guelph

Keywords:
herbicide injury; herbicide drift; herbicide residue analysis

Nomenclature:
2,4-D; dicamba; cucumber; *Cucumis sativus*, L.; cantaloupe; *Cucumis melo* var. *cantalupo*; Ser.

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Effects of low-dose applications of 2,4-D and dicamba on cucumber and cantaloupe

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Abstract

Agronomic crops engineered with resistance to 2,4-D or dicamba have been commercialized and widely adopted throughout the United States. Because of this, increased use of these herbicides in time and space has increased damage to sensitive crops. From 2014 to 2016, cucumber and cantaloupe studies were conducted in Tifton, GA, to demonstrate how auxinic herbicides (namely, 2,4-D or dicamba), herbicide rate (1/75 or 1/250 field use), and application timing (26, 16, and 7 d before harvest [DBH] of cucumber; 54, 31, and 18 DBH of cantaloupe) influenced crop injury, growth, yield, and herbicide residue accumulation in marketable fruit. Greater visual injury, reductions in vine growth, and yield loss were observed at higher rates when herbicides were applied during early-season vegetative growth compared with late-season with fruit development. Dicamba was more injurious in cucumber, whereas cantaloupe responded similarly to both herbicides. For cucumber, total fruit number and relative weights were reduced (16% to 19%) when either herbicide was applied at the 1/75 rate 26 DBH. Cantaloupe fruit weight was also reduced 21% and 10% when either herbicide was applied at the 1/75 rate 54 or 31 DBH, respectively. Residue analysis noted applications made closer to harvest were more likely to be detectable in fruit than earlier applications. In cucumber, dicamba was detected at both rates when applied 7 DBH, whereas in cantaloupe, it was detected at both rates when applied 18 or 31 DBH in 2016 and at the 1/75 rate applied 18 or 31 DBH in 2014. Detectable amounts of 2,4-D were not observed in cucumber but were detected in cantaloupe when applied at either rate 18 or 31 DBH. Although early-season injury will more likely reduce cucumber or cantaloupe yields, the quantity of herbicide residue detected will be most influenced by the time interval between the off-target incident and sampling.

Introduction

Herbicide resistance threatens farm sustainability, with more than 150 unique cases confirmed in the United States to date (CAST 2012; Evans et al. 2015; Heap 2019; Menalled et al. 2016; Rubin 2015; Yu and Powles 2014). Although resistance to acetolactate synthase inhibitors, acetyl coenzyme-A carboxylase inhibitors, and triazines are prevalent, glyphosate resistant weeds are the primary management concern in many major agronomic crops, including corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and cotton (*Gossypium hirsutum* L.) (Riar et al. 2013; Schuster and Smeda 2007; Sosnoskie and Culpepper 2014). To combat glyphosate-resistant weeds, some crop cultivars have been genetically engineered with additional resistance to 2,4-D or dicamba (Behrens et al. 2007; Gressel et al. 2017). Weed management programs using 2,4-D and dicamba have proven effective against some of the most problematic broadleaf weeds in the United States, including Palmer amaranth (*Amaranthus palmeri* S. Watson), common waterhemp [*A. tuberculatus* (Moq.) J. D. Sauer] (Meyer et al. 2015), horseweed (*Conyza canadensis* L.) (Kruger et al. 2010), and giant ragweed (*Ambrosia trifida* L.) (Barnett et al. 2013).

The rapid and widespread adoption of 2,4-D and dicamba resistant crops has increased the spatiotemporal use of these herbicides, resulting in concerns about the potential for increased off-target events due to particle drift, volatility, or spray-tank contamination (Culpepper et al. 2018; Inman et al. 2020; Mueller and Steckel 2019; Vieira et al. 2020). Many specialty crops, such as fruits and vegetables, do not possess natural or engineered resistance to these herbicides. Injury from low rates of auxinic herbicides has been noted in many specialty crops, including snap beans (*Phaseolus vulgaris* L.), potatoes (*Solanum tuberosum* L.), bell pepper (*Capsicum annuum* L.), squash (*Cucurbita pepo* L.), watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai], and wine grapes (*Vitis vinifera* L.) (Colquhoun et al. 2014; Culpepper et al. 2018; Dittmar et al. 2016; Mohseni-Moghadan et al. 2016).

In total, growers in the state of Georgia produce more than 30 unique, high-value fruit and vegetable crops with a farmgate value of more than $1.8 billion, making fruit and vegetable production a vital part of Georgia's agricultural economy (USDA-NASS 2019a, 2019b; Wolfe and Stubbs 2019). In the United States, in 2018, approximately 45,000 ha of cucumber and 25,000 ha of cantaloupe, worth $323 million and $332 million, respectively, were harvested (USDA-NASS 2019b). In the same year, approximately 3,600 ha of cucumber and 900 ha of cantaloupe worth $84 million and $14 million, respectively, were harvested in Georgia (Wolfe and Stubbs 2019). Georgia cucumber production ranked fourth in the United States in hectares harvested and third in value, whereas cantaloupe production ranked third in the United States in hectares harvested and fourth in value. Although specialty crops are vital to Georgia growers, agronomic crops remain a major component of agriculture in the state, with cotton being the most valuable. In 2018, cotton was produced on nearly 570,000 ha, with a value exceeding $790 million (Wolfe and Stubbs 2019).

In the same year, 84% of cotton varieties planted were tolerant to topical applications of either 2,4-D or dicamba (USDA-AMS 2020). The increased spatiotemporal use of 2,4-D and dicamba accompanied by the use of resistant crop cultivars has increased the potential to negatively affect the growth and development of specialty crops (Randell et al. 2020). In Georgia, the counties where the majority of cotton is produced also account for at least $50,000 worth of fresh fruits and vegetables produced per county (Wolfe and Stubbs 2019). Therefore, the potential exists for off-target herbicide application incidents to affect high-value fruit and vegetable crops. The objective of this study was to help growers and the Georgia Department of Agriculture better understand how low doses of 2,4-D and dicamba influence visual injury, vine growth, yield, and the accumulation of herbicide residues in marketable fruit of cucumber and cantaloupe as a response to crop maturity at the time of application.

Materials and Methods

Site Selection and Trial Establishment

Two experiments, one in cucumber and one in cantaloupe, were each conducted twice from 2014 to 2016 at the Tifton Vegetable Park in Tifton, GA (31.45°N, 83.51°W) to evaluate the impact of low doses of 2,4-D and dicamba on visual injury, vine growth, crop yield, and herbicide residues in marketable fruit. Soil at the Tifton Vegetable Park is a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudult) with 84% sand, 11% silt, 5% clay, 0.5% organic matter, and a pH of 6.5. Soil within the experimental area was tilled in January of each year. Within 2 wk, raised beds (0.9 m wide, 7.5 m long, and 15 cm tall) were formed using a combination bed shaper and plastic mulch layer (Kennco Manufacturing, Inc., Ruskin, FL). As beds were formed, the entire trial area was treated with 468 L ha^{-1} of the fumigant dimethyl disulfide mixed with chloropicrin (79:21) (Paladin Pic-21; Arkema, King of Prussia, PA), which was injected 20 cm below the bed top using three shanks evenly spaced across the bed. Drip tape was laid in the center of the bed 2.5 cm below the bed surface as fumigation occurred. Cantaloupe beds were covered with a black-on-black, impermeable film for spring production; in cucumber beds, black-on-white impermeable film was used with the white side facing up for fall production (Guardian Agro Plastics, Tampa, FL).

On the day of planting, transplant holes were mechanically made in the plastic mulch using a transplant hole-punch wheel (Kennco Manufacturing). Cucumber were direct seeded on August 8, 2014, and August 14, 2015, with the cultivars 'Impact' (2014) and 'Bristol' (2015), the most common cultivars grown during each season. 'Aphrodite' cantaloupe were transplanted on April 4, 2014, and March 24, 2016. For both crops, beds were spaced 183 cm apart with alleys measuring 460 cm wide. Cucumber was planted 31 cm apart and cantaloupe was planted 61 cm apart resulting in 20 and 12 plants plot^{-1}, respectively. Cucumber and cantaloupe management including fertility, irrigation, and insect and disease management were conducted in accordance with university recommendations for the region (Kemble et al. 2019).

The experimental design was a randomized complete block design with an augmented factorial arrangement of treatments, consisting of two herbicides, two rates, and three application timings with a nontreated control, resulting in 13 treatments replicated four times. Herbicides used included 2,4-D (Weedar 64®; Nufarm, Inc., Alsip, IL) and dicamba (Clarity®; BASF Corporation, Research Triangle Park, NC). These formulations were used because, at the time of these studies, Enlist One™ (Corteva Agriscience, Indianapolis, IN), Engenia® (BASF Corporation, Research Triangle Park, NC), Xtendimax™ (Bayer CropScience, St. Louis, MO), or Fexapan® (Corteva Agriscience) were not commercially available. Both crops were treated with herbicide rates that were either 1/75 or 1/250 of the recommended field use rates of 2,4-D or dicamba (1,120 and 560 g ae ha^{-1}, respectively). Rates correspond to 14.9 and 4.5 g ae ha^{-1} of 2,4-D and 7.5 and 2.2 g ha^{-1} of dicamba. These rates were selected in response to historical complaint investigations by the Georgia Department of Agriculture and University of Georgia Cooperative Extension Service (Culpepper et al. 2019, 2020).

Cucumbers were treated at approximately 26, 16, or 7 d before harvest (DBH). The 26 DBH applications were made on August 22, 2014, and September 2, 2015. When treated, cucumber plants were 5 to 8 cm tall with one to two leaves. The 16 DBH applications were made September 1, 2014, and September 11, 2015, when vines were 25 to 28 cm long with seven to eight true leaves and plants were in bloom. The 7 DBH applications were made on September 10, 2014, and September 20, 2015, when cucumber vines were 56 to 64 cm long with fruit up to 5 cm long. Cantaloupes were treated at approximately 54, 31, and 18 DBH. The 54 DBH applications were made on April 24, 2014, and April 11, 2016. When treated, cantaloupe plants were 14 cm tall with seven to eight leaves. The 31 DBH applications were made May 17, 2014, and May 1, 2016, when vines were 76 to 80 cm long and plants were in bloom. The 18 DBH applications were made on May 30, 2014, and May 13, 2016, when cantaloupe vines were 114 to 120 cm long and with fruit up to 12 cm in diameter.

Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1}. Booms used were 138 cm long with nozzles spaced 46 cm apart, with a boom height of 45 cm. Separate booms, used exclusively for each respective herbicide chemistry, were used to apply each herbicide. 2,4-D was applied with 11002 AIXR nozzles and dicamba was applied with 110015 TTI nozzles (TeeJet Technologies, Wheaton, IL). Nozzle selection was based on future labels for 2,4-D and dicamba in-crop applications. To avoid physical drift, distances between plots were great (366 to 460 cm), applications were made when wind speeds were minimal, boom height was minimized, and a board was carried on the downwind side of each plot to prevent particle drift. At the time of application for cucumber and cantaloupe experiments, air temperature ranged from 23 to 27 C and 17 to 27 C, respectively; relative humidity ranged from 86% to 89% and 55% to 90%, respectively; and wind speeds did not exceed 2 km h^{-1} and 5 km h^{-1}, respectively.

Data Collection

Visual crop injury (i.e., epinasty, leaf deformations, and chlorosis) was rated on a scale from 0% to 100%, with 0% being no visual injury and 100% being total crop death. For each study, visual injury was evaluated at least every 7 d beginning 1 to 7 d after the first application date. Maximum injury was noted for cucumber at 9 d after each respective application and for cantaloupe at 14 d after each respective application, and only these evaluations are discussed. Vine lengths were measured on 9 to 10 plants plot^{-1} by measuring from the base of the plant to the tip of the longest vine at 2 wk after the final application to quantify crop stunting over the entire growing season. Cucumbers and cantaloupe were harvested 10 to 13 and 11 to 17 times, respectively, and all fruit were counted and weighed at each harvest. In both experiments, the first two mature fruit from each plot were harvested separately and immediately taken to the Georgia Department of Agriculture in preparation for residue analysis. Weights from these fruit were included in both early-season and total yield data. Each plot sample collected for residue analysis, including the nontreated control, was analyzed for both 2,4-D and dicamba.

Residue Analysis

Cucumber and cantaloupe from each plot were cut into cubes measuring 5 cm^3. Cubes were then placed into a Robot Coupe chopper (Robot Coupe U.S.A., Inc., Ridgeland, MS) until the chopper reservoir was half full. The tissue was blended until no large chunks were visible. The homogenized sample was then placed in a sample container and appropriately labeled for cataloging and storage. Knives, chopping boards, and Robot Coupe reservoirs and blades were all triple rinsed with acetone between samples. Robot Coupe tops were triple rinsed with methanol, and the counter was cleaned with acetone. Five grams of cucumber and cantaloupe from each plot were transferred into a 50-mL centrifuge vial and 10 mL of megaohm water was added. Subsequently, 300 μL of a 5N sodium hydroxide solution was added, and the solution was shaken vigorously for 1 min. After 30 min, 300 μL of 5N sulfuric acid solution was added, followed by 10 mL of acetonitrile. The resulting solution was again shaken vigorously for 1 min. After this agitation, 4 g magnesium sulfate, 1 g sodium chloride, 1 g trisodium citrate dihydride, and 0.5 g disodium citrate sesquihydrate were added and the mixture was shaken vigorously for 1 min. The mixture was then centrifuged for 5 min at 3,000 rpm, and the top layer was filtered and removed for analysis.

Residue detection for each plot sample was performed with a Shimadzu Prominence 20A Series LC (Shimadzu Scientific Instruments, Columbia, MD) with an AB Sciex API 3200 Mass Spectrometer (AB Sciex LLC, Framingham, MA) as well as a Shimadzu Prominence 20A Series LC with an AB Sciex Q-Trap 5500 Mass Spectrometer detector. Chromatography used 0.1% acetic acid in water and 0.1% acetic acid in acetonitrile for the mobile phases with an Agilent Zorbax Eclipse XDB-C18 column (Agilent Technologies, Inc, Santa Clara, CA) to separate the desired compounds.

Statistical Analysis

Data were subjected to ANOVA using PROC GLIMMIX in SAS, version 9.4 (SAS Institute, Cary, NC) to determine if herbicide, herbicide rate, and application timing influenced crop injury, vine length, and crop yield. All possible interactions were evaluated and compared with the nontreated control using methods described by Piepho et al. (2006). Significant interactions are reported. Injury, vine length, and yield were set as the response variables with replication and year included in the model as random factors. Treatment-by-year interactions were evaluated and were not significant for any response variable in either crop. Therefore, all data are averaged over year. All P values for tests of differences between least-squares means were compared and adjusted using the Tukey-Kramer method ($\alpha = 0.05$). The Tukey-Kramer method was chosen because it reduces type I error compared with the Fisher's protected LSD when more than three means are compared with each other, and it can also be used for balanced designs (Blythe 2012; Westfall et al. 2011).

Results and Discussion

Cucumber Response

Cucumber injury at 9 d after application (DAA) was affected by the interactions of rate and application timing and of herbicide and rate. Cucumbers treated with dicamba at the 1/75 rate (22% injury) had higher injury levels than cucumbers treated with the same relative rate of 2,4-D (15% injury) when averaged over application timings (data not shown). This trend remained true for the 1/250 rates, with dicamba causing greater visual injury than 2,4-D (10% and 6%, respectively). These data indicate that low rates of dicamba are more injurious to cucumber than 2,4-D. With respect to the rate and application timing interaction, the 1/75 rates resulted in a higher level of injury than the 1/250 rates when averaged over herbicide applied (Table 1). When averaged over herbicide, cucumber injury at 26, 16, and 7 DBH was 23%, 17%, and 16%, respectively, for the 1/75 rate and ranged from 7% to 9% for the 1/250 rate (Table 1). Applications of the higher rate made when cucumbers were vegetatively growing were most injurious. Previous studies have produced similar results, with greater levels of injury occurring when the plants were treated with higher herbicide rates at vegetative growth stages (Byrd et al. 2016; Culpepper et al. 2018). In the cucumber trial, cucumbers treated at 26 DBH had not begun to flower, whereas cucumbers treated at 16 DBH were beginning to bloom, and cucumbers treated at 7 DBH had immature fruit on the vines.

Vine length was also affected by the interaction between herbicide and rate and the interaction between application timing and rate. Averaged over application timing, the 1/75 rate of dicamba resulted in a 23% reduction in vine length compared with the control. Although not as severe, the 1/75 rate of 2,4-D also reduced vine length compared with the control (7% reduction). This again demonstrates the higher level of cucumber sensitivity to dicamba. Similar to injury, a greater reduction in vine growth was noted with younger plants and at higher rates (Table 1). Averaged over herbicide applied, the 1/75 rate applied 26 and 16 DBH resulted in 18% and 10% reductions in vine length compared with the control, respectively. In addition, the 1/250 rate applied 26 DBH also resulted in significant vine length reduction, albeit not as severe as the higher rate.

Low doses of auxinic herbicides could potentially delay maturity, as demonstrated by Culpepper et al. (2018) in watermelon. In addition, delays in maturity from low-dose applications of 2,4-D or dicamba have been demonstrated in cotton and soybean (Byrd et al. 2016; Russell et al. 2020; Scholtes et al. 2019). Any delay in maturity could reduce the value of vegetable crops. Early-season cucumber fruit counts and weights (harvests 1–4) were used to quantify possible maturity delays. Harvest data were not affected

Table 1. Cucumber response to low-dose applications of 2,4-D or dicamba with respect to relative rate applied and application timing.[a]

				Harvests 1–4[d]		Harvests 1–13[d]	
Relative rate[b]	Application timing[c]	Injury[d,e]	Vine length[d]	No. of fruit	Fruit weight	No. of fruit	Fruit weight
	DBH	%	cm	no. ha^{-1}	kg ha^{-1}	no. ha^{-1}	kg ha^{-1}
1/75	26	23 a	75 d	22,387 c	4,594 c	67,627 b	16,187 b
	16	17 b	83 c	31,170 bc	5,411 bc	74,959 a	18,538 a
	7	16 b	90 a	45,223 ab	6,684 ab	78,972 a	19,609 a
1/250	26	7 c	86 b	34,683 bc	5,890 abc	78,994 a	19,971 a
	16	9 c	91 a	49,174 a	7,151 a	78,378 a	19,553 a
	7	8 c	92 a	34,683 bc	5,759 abc	76,674 a	19,261 a
NTC[c]		0 d	92 a	43,037 ab	6,609 ab	80,022 a	20,060 a

[a] Data are pooled over herbicide applied and year.

[b] Relative rates correspond to 1,120 and 560 g ai ha^{-1} of 2,4-D and dicamba, respectively.

[c] Abbreviations: DBH, days before harvest; NTC, nontreated control.

[d] Means followed by the same letter in a column do not differ significantly ($P \leq 0.05$).

[e] Injury ratings reported were evaluated 9 d after application.

by year and were combined for analysis. In the control, 43,037 fruit ha^{-1} were harvested with a weight of 6,609 kg ha^{-1} for harvests 1 through 4 (Table 1). Herbicide option was not influential, but herbicide rate and application timing influenced yield. Pooled over herbicide, the 1/75 rate reduced fruit numbers 48% and weights 30% when applied 26 DBH. Yield loss was not observed with the higher rate applied at 16 or 7 DBH or with the 1/250 rate at any application timing.

Fruit count and weight for the entire season were not significantly affected by year; therefore, data were combined for analysis and presentation. Fruit count and weight were influenced by the interaction between rate and application timing. Nontreated control plots yielded 80,022 fruit ha^{-1} with a respective weight of 20,060 kg ha^{-1} (Table 1). Only the 1/75 rate applied at 26 DBH, averaged over herbicides, significantly differed from the control (67,627 fruit ha^{-1} weighing 16,187 kg ha^{-1}).

In both 2014 and 2015, no herbicide residue was detected in cucumber fruit treated with 2,4-D, regardless of rate or application timing (Table 2). In addition, no dicamba residue was detected at the 26 or 16 DBH timings, regardless of rate in either year. For dicamba applied 7 DBH at the 1/75 and 1/250 rates, laboratory testing identified herbicide residue at concentrations of 0.02 and 0.007 ppm, respectively, in 2014, and 0.05 and 0.02 ppm, respectively, in 2015. No residues were found in any sample collected from the nontreated control for both years. In addition, dicamba was never detected in samples treated with 2,4-D and vice versa.

Cantaloupe Response

Cantaloupe injury at 14 DAA was influenced by the interaction of herbicide and application timing, as well as rate and application timing. With respect to the herbicide and application timing interaction, injury only differed between herbicides when applied 31 DBH with dicamba applications resulting in higher injury than 2,4-D (16% and 11% injury, respectively) (data not shown). Injury was similar among herbicides when applied 54 DBH (19% to 20% injury) and 18 DBH (3% to 5% injury). When averaged over herbicides, cantaloupe injury for the 1/75 rate was 26%, 19%, and 5% when applied 54, 31, and 18 DBH, respectively, and 13%, 9%, and 3% for the 1/250 rate applied at the aforementioned intervals (Table 3). Similar responses were noted with the cucumber experiment, with greater injury observed when cantaloupe was treated during vegetative growth stages and at higher rates.

Vine length was affected by the interaction of rate and application timing. Compared with the control and pooled over herbicides, the 1/75 rate applied 54 and 31 DBH reduced vine length 19% and 6%, respectively (Table 3). The 1/250 rate also reduced vine length at the aforementioned application timings by 11% and 4%, respectively. Vine lengths were no different than the control when applications were made 18 DBH.

Fruit number and relative weight from early-season cantaloupe harvests (harvests 1 through 5) were calculated to again determine treatment effects on crop maturity. Averaged over years, fruit counts and weights were influenced by the interaction of rate and application timing. Cantaloupe in the control plots for the first five harvests yielded 12,889 fruit ha^{-1} at a respective weight of 33,842 kg ha^{-1}(Table 3). Only the 1/75 rate applied at 54 DBH resulted in a significant reduction in early-season yield compared with the control (9,756 fruit ha^{-1} weighing 22,433 kg ha^{-1}).

Fruit number and weight for the entire season, when pooled over year, was affected by the interaction of rate and application timing. On average, cantaloupe in the nontreated plots yielded 26,450 fruit ha^{-1} weighing 78,503 kg ha^{-1} (Table 3). Averaged over herbicides, fruit number was significantly reduced when a 1/75 rate was applied 54 DBH (21,782 fruit ha^{-1}). In addition, fruit weight loss of 21% and 10% was noted with the 1/75 rate applied 54 and 31 DBH, respectively.

In 2014, no herbicide residues were detected when cantaloupe were treated with 2,4-D, regardless of rate or timing (Table 3). However in 2016, 2,4-D was detected at concentrations of 0.001 and 0.004 ppm when applied at the 1/75 rate at 31 and 18 DBH, respectively. When treated with a 1/250 rate of 2,4-D at 31 and 18 DBH, laboratory testing identified herbicide residue at concentrations of 0.0003 and 0.001 ppm. Concerning dicamba, no residues were detected in cantaloupe treated at the 54 DBH timing, regardless of year. In 2014, when cantaloupe were treated with a 1/75 rate of dicamba at 31 and 18 DBH, laboratory testing identified herbicide residue at concentrations of 0.005 and 0.014 ppm. No residues were detected from the 1/250 rate of dicamba in 2014. In 2016, when cantaloupe were treated with a 1/75 rate of dicamba at 31 and 18 DBH, laboratory testing identified herbicide residue at concentrations of 0.0008 and 0.008 ppm, respectively; when treated with a 1/250 rate of dicamba at 31 and 18 DBH, laboratory testing identified herbicide residue at concentrations of 0.0003 and 0.001 ppm. No residues were found in any samples collected from the nontreated control in either year; dicamba was never detected in samples treated with 2,4-D and vice versa.

Off-target movement of auxinic herbicides can be detrimental to cucumber and cantaloupe crops by causing visual injury, reducing vine growth, and negatively affecting yield. Furthermore,

Table 2. Herbicide residues detected in marketable cucumber and cantaloupe fruit as influenced by auxinic herbicide, rate, and application timing with respect to days before harvest from 2014 to 2016.

		Cucumber			Cantaloupe		
			Year			Year	
Herbicide	Rate	Application timing[a]	2014	2015	Application timing	2014	2016
		DBH	———PPM———		DBH	———PPM———	
Dicamba	1/75	26	0.0	0.0	54	0.0	0.0
		16	0.0	0.0	31	0.005	0.0008
		7	0.02	0.05	18	0.014	0.008
	1/250	26	0.0	0.0	54	0.0	0.0
		16	0.0	0.0	31	0.0	0.0003
		7	0.007	0.02	18	0.0	0.001
2,4-D	1/75	26	0.0	0.0	54	0.0	0.0
		16	0.0	0.0	31	0.0	0.001
		7	0.0	0.0	18	0.0	0.004
	1/250	26	0.0	0.0	54	0.0	0.0
		16	0.0	0.0	31	0.0	0.0003
		7	0.0	0.0	18	0.0	0.001

[a] Abbreviations: DBH, days before harvest; PPM, parts per million.

Table 3. Cantaloupe response to low dose applications of 2,4-D or dicamba with respect to relative rate applied and application timing.[a]

				Harvests 1–5		Harvests 1–17	
Relative rate[b]	Application timing[c]	Injury[d,e]	Vine length[d]	No. of fruit[d]	Fruit weight[d]	No. of fruit[d]	Fruit weight[d]
	DBH	%	cm	no. ha^{-1}	kg ha^{-1}	no. ha^{-1}	kg ha^{-1}
1/75	54	26 a	142 e	9,756 b	22,433 b	21,782 b	62,193 c
	31	19 b	164 c	11,674 ab	30,245 a	25,421 a	70,843 b
	18	5 de	174 ab	12,889 a	35,873 a	25,699 a	80,379 a
1/250	54	13 c	156 d	12,898 a	30,289 a	27,000 a	75,914 ab
	31	9 cd	168 bc	13,599 a	34,993 a	27,857 a	79,531 a
	18	3 e	175 a	12,986 a	35,277 a	26,439 a	81,023 a
NTC[c]		0 e	175 a	12,889 a	33,842 a	26,450 a	78,503 a

[a] All data are pooled over year and herbicide applied.
[b] Relative rates correspond to 1,120 and 560 g ai ha^{-1} of 2,4-D and dicamba, respectively.
[c] Abbreviations: DBH, days before harvest; NTC, nontreated control.
[d] Means followed by the same letter in a column do not differ significantly ($P \leq 0.05$).
[e] Injury ratings reported were evaluated 14 d after application.

residue detection in marketable fruit can be devastating to growers when the fruit are affected by herbicide drift. In both cucumber and cantaloupe, the factor with the greatest influence on visual injury, vine length reductions, and yield reductions was growth stage at the time of application, which was similarly reported for watermelon by Culpepper et al. (2018). Although visual injury, vine length reductions, and yield reductions were more negatively affected when applications were made at early growth stages, residue detection was more likely to occur at later application dates, when fruit were closer to harvest. Generally, the 1/75 rate resulted in a more negative impact than the 1/250 rate. Although herbicide was not a significant factor in the cantaloupe experiments, dicamba applications resulted in greater visual injury, vine length reductions, and higher residue detection in cucumber than 2,4-D.

Acknowledgements. The authors thank Tim Richards for his technical expertise and would also like to acknowledge the hard work and dedication of the student workers at the time of this study. No specific grant from any funding agency, commercial, or not-for-profit sectors was received to support this research. No conflicts of interest have been declared.

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