Weed Technology

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Research Article

Cite this article: Polli EG, Gannon TW, LeCompte M, Rogers RR, Beran DD (2024). Response of soybean, cotton, and tobacco to volatility of 2,4-D and dicamba formulations in humidome. Weed Technol. **38**(e21), 1–7. doi: 10.1017/wet.2023.86

Received: 20 September 2023
Revised: 10 November 2023
Accepted: 15 November 2023

Associate Editor:
Kevin Bradley, University of Missouri

Nomenclature:
2,4-D; dicamba; cotton, *Gossypium hirsutum* L.; soybean, *Glycine max* (L.) Merr.; tobacco, *Nicotiana tabacum* L.

Keywords:
vapor drift; volatilization; synthetic-auxin herbicides; row crops

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Response of soybean, cotton, and tobacco to volatility of 2,4-D and dicamba formulations in humidome

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Abstract

Dicamba and 2,4-D are postemergence herbicides widely used to control broadleaf weed species in crop and non-crop areas in the United States. Currently, multiple formulations of 2,4-D and dicamba are available on the market. Even though the active ingredient is the same, the chemical formulation may vary, which can influence the volatility potential of these herbicides. Therefore, the objective of this study was to evaluate the response of soybean, cotton, and tobacco plants exposed to vapors of 2,4-D and dicamba formulations alone or mixed in humidomes for 24 h. Humidome studies were conducted in an open pavilion at the Lake Wheeler Turfgrass Field Lab of the North Carolina State University in Raleigh, NC. Dicamba and mixture treatments injured and caused a reduction in the height of soybean. Injury varied from 55% to 70%, and average plant height was 8.8 cm shorter compared with untreated control plants. Treatments with 2,4-D caused the least injury to soybean (≤21%), and differences among formulations were identified (dimethylamine > choline > dimethylamine-mono-methylamine). However, soybean height was not affected by 2,4-D treatments. No differences between treatments were observed when herbicides were applied to cotton. The greatest injury to tobacco (23.3%) was caused by dicamba dimethylamine. Overall, the effect of 2,4-D and dicamba vapor was species-specific and formulation-dependent. Additionally, environmental conditions in the humidomes may have played a major role on the outcome of this study.

Introduction

Dicamba and 2,4-D are postemergence herbicides commonly used to control broadleaf weeds in agricultural and nonagricultural systems in the United States. The estimated agricultural use of 2,4-D and dicamba was 50 and 32 million pounds of active ingredient in 2019, respectively (USGS 2021). Furthermore, the United States Environmental Protection Agency ranked 2,4-D the first and dicamba the eighth most used herbicides in nonagricultural systems in 2012 (US EPA 2017). However, concerns regarding the volatility potential of these herbicides have significantly increased in recent years due to the great increase in planting crops that are resistant to 2,4-D and dicamba (Dodson et al. 2021; Wechsler et al. 2019).

Dicamba and 2,4-D are synthetic auxin herbicides, categorized by the Weed Science Society of America as Group 4, or growth regulator herbicides. These herbicides act by mimicking the natural plant hormone indole-3-acetic acid (Grossmann 2007), which causes leaf cupping, malformation, stem epinasty (Ahrens 1994), necrosis of terminal meristematic tissues followed by reduced root and shoot growth (Tehranchian et al. 2017; Grabińska-Sota et al. 2003), and ultimately, plant death. Numerous studies have reported that sublethal doses of 2,4-D and dicamba can seriously injure sensitive ornamental and susceptible crop species; for example, soybean, cotton, flue-cured tobacco, and several fruit and vegetable crops (Culpepper et al. 2018; Dintelmann et al. 2020; Dittmar et al. 2016; Egan et al. 2014; Gilreath et al. 2001; Hemphill and Montgomery 1981; Johnson et al. 2012; Mohseni-Moghadam et al. 2016). In a study conducted by Egan and Mortensen (2012), dicamba vapor from doses as low as 0.1% (0.56 g ae ha^{-1}) of the concentration applied to injured soybean plants located 21 m away from the application area.

According to Riter et al. (2020), the concentration of a herbicide in the air as a vapor and its potential to move off target are a function of environmental conditions and properties of the herbicide active ingredient and formulation. Air and soil temperature, air relative humidity, wind direction, rainfall, and application surface are the main conditions that affect herbicide volatility (Mueller and Steckel 2019, 2021; Ouse et al. 2018). In terms of herbicide properties, vapor pressure (VP) is the key parameter that controls vapor behavior (Spencer and Cliath 1983). Volatile herbicides usually have higher VP than nonvolatile herbicides. Dicamba and 2,4-D are classified as moderately volatile herbicides. Nevertheless, dicamba has a higher VP and is considerably more volatile than 2,4-D (Mueller et al. 2022). Moreover, some formulations are more prone to volatilization than others.

The 2,4-D herbicide is formulated in three chemical forms: acid, ester, and salt. Even though 2.4-D acid has a low VP, its low water solubility prevents its use as a herbicide. Thus, 2,4-D commercial formulations include only ester and salts. The 2,4-D ester has the highest VP (480 μPa), followed by choline salt (19 μPa), and then dimethylamine salt (13 μPa) (Gervais et al. 2008; MDA 2015). Havens et al. (2018) reported that 2,4-D choline was 88% and 96% less volatile than 2,4-D amine and 2,4-D ester, respectively. Dicamba commercial formulations are available in acid and salt forms, such as diglycolamine (DGA) and dimethylamine (DMA). The dicamba parent acid has a VP of 4,500 μPa, which is significantly higher than the VP of DGA and DMA salts (Hartzler 2017). Furthermore, dicamba DMA has a higher VP than dicamba DGA (Egan and Mortensen 2012; Mueller and Steckel 2019). According to a report by Mueller et al. (2013), the concentration of dicamba DMA in the air was 2-fold higher than dicamba DGA.

Although previous researchers have investigated the difference between 2,4-D and dicamba formulations, information regarding the volatility potential of new formulations such as 2,4-D dual-salt (dimethylamine + monomethylamine), and 2,4-D + dicamba formulations commonly used on turfgrass and pasture systems are scarce in scientific literature. Additionally, a limited number of vapor studies have been conducted to compare the effect of 2,4-D and dicamba formulations on soybean, cotton, and tobacco plants in humidomes. Employing humidomes in vapor studies offers several advantages, such as the ability to perform multiple herbicide treatments simultaneously under consistent environmental conditions, all within the same timeframe, and without the risk of cross-contamination. Therefore, the objective of this study was to evaluate the response of soybean, cotton, and tobacco plants exposed to vapors of 2,4-D and dicamba formulations alone or mixed in humidomes for 24 h.

Materials and Methods

Experimental Site and Design

Studies were conducted in an open pavilion at the Lake Wheeler Turfgrass Field Laboratory of the North Carolina State University in Raleigh, NC. The experiment consisted of a complete randomized block design containing three replications. Two experimental runs of soybean and tobacco studies were conducted in October 2021, and two experimental runs of cotton and tobacco studies were carried out in October 2022.

Plant Material

Soybean ('CZ6520'; BASF Corporation, Florham Park, NJ) and cotton ('ST4550GLTP'; BASF Corporation) plants were grown in 10- × 10- × 10-cm pots using 1:1 sand and Pro-Mix BX5 (Premier Tech Horticulture Ltd., Riviere-du-Loup, QC, Canada). Flue-cured tobacco cultivar ('NC 196'; Gold Leaf Seed Co., Hartsville, SC) was seeded in greenhouse float systems, and once plants reached 10 cm in height, they were transplanted to 15- × 15- × 20-cm pots filled containing the same soil mix mentioned above. The greenhouse temperature was maintained between 18 and 28 C with 60% ± 10% relative humidity. Supplemental LED lighting of 520 μmol s^{-1} (Philips Lighting, Somerset, NJ) was provided to extend the daylight period to 16 h. Plants were watered daily and fertilized (Peters Professional 20-20-20 Water Soluble Fertilizer; Scotts-Sierra Horticultural Products Company, Maryville, OH) weekly. The study was initiated once soybean plants reached the second trifoliate leaf growth stage (V2), when the second true leaf had fully developed in cotton plants, and once tobacco plants had four fully expanded leaves. On the day before study initiation, sod was harvested from a field of 'Tifway 419' bermudagrass [*Cynodon transvaalensis* Burtt Davy × dactylon (L.) Pers.] at the Lake Wheeler Turfgrass Field Laboratory that had been maintained at 6 cm and cut in 18- × 15-cm pieces to fit in 19- × 16-cm aluminum trays.

Herbicide Treatments and Spray Application

Treatments included commercial and experimental 2,4-D and dicamba formulations (Table 1), and one untreated control. For each treatment, two sod trays were sprayed using a three-nozzle, handheld CO_2-pressurized backpack sprayer (Bellspray Inc., Opelousas, LA) calibrated to deliver 304 L ha^{-1} through TeeJet XR8002 nozzles (Spraying Systems Co., Glendale Heights, IL) at 124 kPa. Nozzle spacing and boom height were both set at 25.4 cm, and the application speed was 1.3 m s^{-1}. To avoid cross-contamination, sod trays were sprayed 166 m away from the experimental site and then immediately transported to the experimental site in the back of a golf utility vehicle that was covered with new plastic sheets between each treatment.

Humidome

Humidomes consisted of two clear polycarbonate pans (Vigor; The WEBstaurant Store LLC, Lancaster, PA) measuring 53 cm long, 30 cm wide, and 20 cm deep. One hole (0.625-cm diam) was drilled into each pan approximately 5 cm from the base. A plastic valve was inserted into the holes where tubes were attached to 5-m-long flexible tubes (3 mm internal diam) and then connected to a four-port or five-port manifold for air inlet and outlet ports. The inlet and outlet air systems were connected to the valves in the bottom and upper pan, respectively, and were positioned in opposite directions. The air inlet manifolds were connected to a funnel (20 cm diam) through a 10-m flexible air tubing (6 mm internal diam). The air outlet manifolds were connected to 3-m flexible air tubing (6 mm internal diam) that was attached to an air vacuum pump (Marathon Electric ¼ horsepower; Regal Beloit Corp., Wausau, WI; and Welch 2025 ¼ horsepower; Welch Vacuum Technology Inc., Mount Prospect, IL). One air vacuum pump was used per block to provide an airflow of 2 L min^{-1} for each humidome throughout the duration of the study (Figure 1). Further information regarding the assembly of the humidomes used in this study can be found in Maxwell (2021). An air flow meter (Defender 520; Mesa Laboratories Inc., Lakewood, CO) was used to calibrate the air pumps before each experimental run was initiated. Temperature and relative humidity (RH) in the humidomes were recorded using HOBO® data loggers (Onset®; Bourne, MA) (Table 2). Once the treated sod trays were at the experimental site, they were placed in the humidomes and then cotton, soybean, or tobacco plants were carefully placed and centered between the trays to avoid any contact with sprayed material, and then the humidomes were sealed immediately using tape (Duck; Shurtape Technologies LLC, Hickory, NC) (Figure 2). Humidomes were opened 24 h after treatment and plants were transferred to the greenhouse.

Table 1. Dicamba and 2,4-D formulations.[a]

Herbicide	Commercial name[b]	2,4-D salt	Rate	Dicamba salt	Rate	pH[c]	Common name
			g ae ha^{-1}		g ae ha^{-1}		
2,4-D	NFA-0020104	Dual-salt	1,680	–	–	6.9	2,4-D dual-salt A
2,4-D	NFA-0020110	Dual-salt	1,680	–	–	5.9	2,4-D dual-salt B
2,4-D	Enlist One™	Choline	1,680	–		6.2	2,4-D choline
2,4-D	Weedar 64®	DMA	1,680	–	–	6.2	2,4-D DMA
Dicamba	Clash®	–	–	DGA	560	6.1	Dicamba DGA
Dicamba	Diablo®	–	–	DMA	560	6.0	Dicamba DMA
2,4-D + dicamba	WeedMaster XHL	Dual-salt	1,680	DGA	560	6.5	2,4-D dual-salt + dicamba DGA
2,4-D + dicamba	Range Star® + Weedar 64®	DMA	1,680	DMA	560	6.5	2,4-D DMA + dicamba DMA

[a]Abbreviations: DGA, diglycolamine salt; DMA, dimethylamine salt; dual-salt, dimethylamine and monomethylamine salts.
[b]The experimental formulation of NFA-0020104 was provided by Nufarm America Inc. (Alsip, IL); WeedMaster XHL (registration pending), Weedar 64®, Clash®, and Diablo® were also provided by Nufarm, Inc. Enlist One™ was supplied by Corteva Agriscience (Indianapolis, IN), and Range Star® was supplied by Albaugh, LLC (Ankeny, IA).
[c]The pH of herbicide solutions was measured using a pHmeter (AR 25; Accumet, Thermo Fisher Scientific Inc., Waltham, MA).

Table 2. Air temperature and relative humidity in the humidome during the soybean, cotton, and tobacco studies.[a,b]

	Soybean		Cotton		Tobacco			
Parameter	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 3	Run 4
Temperature	C							
Minimum	20	21	15	11	19	19	18	13
Maximum	34	29	26	30	23	32	31	19
Average	24	24	20	19	20	24	23	17
Relative humidity	%							
Minimum	68	56	78	71	66	54	59	72
Maximum	100	98	100	97	99	98	96	95
Average	94	95	97	91	97	93	85	90

[a]Air temperature and relative humidity in the humidomes were measured for approximately 24 h after herbicide application. Studies were conducted in an open shed at the Turfgrass Research Station of the North Carolina State University in Raleigh, NC.
[b]Experimental runs 1 and 2 for soybean were conducted in October 2021; experimental runs 1 and 2 for cotton were conducted in October 2022; and experimental runs 1 and 2 for tobacco were conducted in October 2021 and experimental runs 3 and 4 were conducted in October 2022.

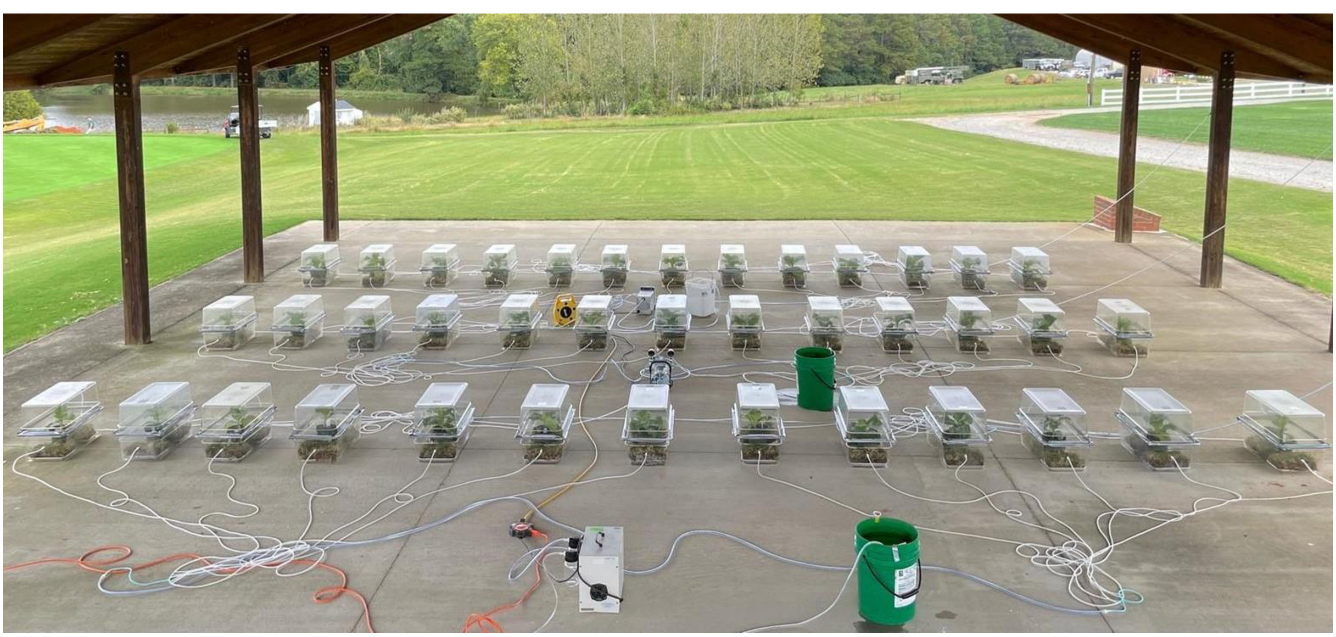

Figure 1. Humidome study in an open pavilion at the Lake Wheeler Turfgrass Field Laboratory in Raleigh, NC. Each humidome contained one tobacco plant between two trays that contained bermudagrass, which was either untreated or treated with a herbicide.

https://doi.org/10.1017/wet.2023.86 Published online by Cambridge University Press

Figure 2. A soybean plant between herbicide-treated bermudagrass trays in a humidome.

Table 3. Effect of herbicide treatments on injury, plant height, and biomass reduction of soybean plants at 28 d after removal from humidomes.[a,b]

Herbicide treatment	Injury	Plant height	Biomass reduction
	%	cm	%
Control	—	29 A	—
Dicamba DMA	70 A	19 B	35.2
Dicamba DGA	64 AB	19 B	22.0
2,4-D dual-salt + dicamba DGA	59 B	21 B	26.2
2,4-D DMA + dicamba DMA	55 B	23 B	8.0
2,4-D DMA	21 C	28 A	13.1
2,4-D choline	13 CD	29 A	7.4
2,4-D dual-salt A	9 D	30 A	8.6
2,4-D dual-salt B	7 D	29 A	2.7
$LSD_{(0.05)}$[c]	11	4	—

[a]Abbreviations: DMA, dimethylamine salt; DGA, diglycolamine salt; dual-salt, dimethylamine and monomethylamine salts.
[b]Means followed by the same letter in a column do not differ according to Fisher's LSD at $\alpha = 0.05$.
[c]Fisher's LSD at $\alpha = 0.05$.

Data Collection and Statistical Analyses

Injury and plant height of crop species were recorded at 28 d after application. A scale ranging from 0% (absence of injury) to 100% (completely plant death) was applied to assess injury. Additionally, aboveground biomass of plants was harvested and oven-dried at 65 C until a constant dry weight was achieved. Dry biomass data were recorded and converted into percentage of biomass reduction for comparison with the untreated control according to Equation 1:

$$BR = 100 - \frac{(X*100)}{Y} \quad [1]$$

where BR is the biomass reduction (%), X is the biomass (in grams) of an individual experimental unit after being treated, and Y is the mean biomass (in grams) of the untreated control replicates.

For each crop species, injury, plant height, and biomass data were subjected to ANOVA using the GLIMMIX procedure with SAS software (version 9.4; SAS Institute Inc., Cary, NC), and treatment means were computed using Fisher's LSD procedure at $\alpha = 0.05$. Experimental run and herbicide treatment were considered fixed effects, and replications as random effects. Additionally, when appropriate, orthogonal contrast analyses were conducted to compare different formulations among herbicides using the GLIMMIX procedure at $\alpha = 0.05$.

Results and Discussion

Soybean

Herbicide treatment resulted in significant injury and plant height, but biomass was not affected ($\alpha = 0.05$). Additionally, because experimental runs were not significantly different, means were pooled among herbicide treatments. The highest injury values occurred with dicamba (67%) and mixture treatments (57%; Table 3). Treatments with 2,4-D presented the lowest injury values, which ranged from 6.7% to 20.8%. While there were no differences between dicamba and mixture formulations, injury from 2,4-D DMA was 18.8% and 21.3% greater than 2,4-D dual-salt A and 2,4-D dual salt B, respectively. Furthermore, orthogonal contrast analysis confirmed a similarity among dicamba and mixture formulations and revealed additional significant differences among 2,4-D formulations at $\alpha = 0.05$ (Table 4). Thus, among 2,4-D formulations, the highest injury values were observed for 2,4-D DMA (21%), followed by 2,4-D choline (13%), then 2,4-D dual-salt A (9.2%), and then dual-salt B (6.7%). Treatments with 2,4-D alone did not affect soybean height when compared with that of the control plants. The average plant height after 2,4-D formulation treatments and control plants was 28.9 cm and 29.3 cm, respectively. In contrast, dicamba and mixture treatments negatively affected soybean height. The average height of soybean plants exposed to these treatments was 8.8 cm shorter than controls. No differences between dicamba and mixture formulations were identified by orthogonal contrast analysis. Unlike injury and plant height, no differences in biomass were observed among herbicide treatments; values ranged from 2.7% to 35.2%.

Table 4. Orthogonal contrasts of 2,4-D and dicamba formulations applied alone or mixed and their effect on soybean injury and plant height at 28 d after removal from humidomes.[a]

Orthogonal contrast	Injury	Plant height
	P-value[b]	
Dicamba DMA × DGA	0.8209	0.6801
Dicamba alone	0.0094	0.0577
2,4-D dual-salt × choline	0.0087	0.2379
2,4-D dual-salt × DMA	0.0004	0.2854
2,4-D choline × DMA	<0.0001	0.0602
2,4-D alone × mixture	<0.0001	<0.0001
Premixture × tank-mixture	0.4252	0.4546

[a]Abbreviations and definitions: DGA, diglycolamine salt; DMA, dimethylamine salt; dual-salt, dimethylamine and monomethylamine salts; mixture, 2,4-D dual-salt + dicamba DGA and 2,4-D DMA + dicamba DMA; premixture, 2,4-D dual-salt + dicamba DGA; tank-mixture, 2,4-D DMA + dicamba DMA.
[b]Significance level, $P \leq 0.05$.

Cotton

Herbicide treatment and experimental runs were not significant for any of the parameters analyzed (injury, plant height, and biomass) at $\alpha = 0.05$. Thus, herbicide treatments tested in this study caused similar injury in cotton plants. Injury values varied from 2.5% to 10% (Table 5). Additionally, cotton height was not affected by herbicide treatments. The average height of plants

https://doi.org/10.1017/wet.2023.86 Published online by Cambridge University Press

Table 5. Effect of herbicide treatments on injury, plant height, and biomass reduction of cotton plants at 28 d after removal from humidomes.[a]

Herbicide treatment	Injury	Plant height	Biomass reduction
	%	cm	%
Control	–	31	–
Dicamba DMA	5	29	−0.4
Dicamba DGA	7	29	5.0
2,4-D Dual-salt + dicamba DGA	7	31	0.6
2,4-D DMA + dicamba DMA	3	29	7.2
2,4-D DMA	10	31	4.3
2,4-D choline	6	29	16.9
2,4-D dual-salt A	6	29	11.8
2,4-D dual-salt B	3	31	3.6

[a]Abbreviations: DGA, diglycolamine salt; DMA, dimethylamine salt; dual-salt, dimethylamine and monomethylamine salts.

Table 6. Effect of herbicide treatments on injury, plant height, and biomass reduction of tobacco plants at 28 d after removal from humidomes.[a]

Herbicide treatment	Injury[b]	Plant height	Biomass reduction
	%	cm	%
Control	–	36	–
Dicamba DMA	23 A	40	12.0
Dicamba DGA	13 B	40	8.8
2,4-D dual-salt + dicamba DGA	12 B	41	6.3
2,4-D DMA + dicamba DMA	13 B	40	3.1
2,4-D DMA	5 B	43	0.5
2,4-D choline	5 B	35	19.6
2,4-D dual-salt A	7 B	42	0.5
2,4-D dual-salt B	10 B	35	8.3
$LSD_{(0.05)}$[c]	8	—	—

[a]Abbreviations: DGA, diglycolamine salt; DMA, dimethylamine salt; dual-salt, dimethylamine and monomethylamine salts.
[b]Means followed by the same letter in the column do not differ according to Fisher's LSD at $\alpha = 0.05$.
[c]Fisher's LSD at $\alpha = 0.05$.

submitted to herbicide treatments was 29.7 cm compared with 30.7 cm for control plants. Similar to injury and plant height, no differences in biomass were observed between herbicide treatments; values varied from −0.4% to 16.9%.

Tobacco

While herbicide treatment caused significant injury, no significant differences were observed in plant height and biomass at $\alpha = 0.05$. Means were pooled among herbicide treatments because experimental runs were not significantly different. The greatest injury was observed with dicamba DGA (23.3%; Table 6). No differences were observed between the other herbicide treatments for which injury varied from 5.4% to 12.9%. Orthogonal contrast analyses indicated a significant difference among 2,4-D and dicamba treatments alone and in mixtures (data not shown). Treatments with 2,4-D and dicamba alone caused greater and less injury, respectively, than mixture treatments. As with cotton, average plant height of treated tobacco plants (39.5 cm) was similar to that of control plants (35.8 cm), and no differences were identified between treatments. Likewise, no differences in biomass were observed between herbicide treatments; values ranged from 0.5% to 19.6%.

Mueller et al. (2013) indicated that the DMA salt of dicamba presented higher vapor potential than the DGA salt of dicamba. Similar results were found by Egan and Mortensen (2012) and Sciumbato et al. (2004). In this present study, no differences were observed in injury, plant height, and biomass of soybean when the dicamba formulations were applied. Weather conditions, alongside formulation, can significantly affect herbicide volatility (Jones et al. 2019; Ouse et al. 2018). In a humidome study conducted by Mueller and Steckel (2019), dicamba concentrations were 95% lower when temperatures were below 15 C compared with temperatures above 30 C. Furthermore, Behrens and Lueschen (1979) demonstrated that soybean exposed to dicamba DMA and diethanolamine vapor in closed jars presented injury that was 12% and 26% greater, respectively, when RH decreased from 85% to 95% to 70% to 75%. This present study was conducted in a shaded environment to avoid extreme air temperatures in the humidome that could lead to damage and death of plants, and to avoid unusual conditions that might exaggerate the formation of vapor. Additionally, evapotranspiration processes resulted in the average air RH remaining high in the humidomes, which is unfavorable to the formation of vapor, but is a common condition observed during the growing season in North Carolina and other southern states. Although the average air temperature in the humidomes was high (≥24 C) throughout the soybean experiments, the high average air RH (≥94%) may have minimized the vapor potential differences among dicamba formulations, which resulted in similar soybean response to the DMA and DGA formulations. However, differences in injury were observed among 2,4-D formulations in soybean (DMA > choline > dual-salt). Ouse et al. (2018) determined that the volatility of 2,4-D DMA was greater than that of 2,4-D choline in chambers where temperatures were held at 30 C or 40 C and RH was 20% or 50%. In the same study, the authors stated that the air concentration of 2,4-D DMA was 80-fold higher than 2,4-D choline. In contrast, Mueller et al. (2022) reported no differences between herbicide air concentrations of 2,4-D DMA and 2,4-D choline when herbicides were applied to green plants or wheat stubble, which is also in accordance with findings reported by Sosnoskie et al. (2015).

There is a lack of information in the scientific literature about volatilization of 2,4-D dimethylamine + monomethylamine (dual-salt). Findings from this study suggest that the addition of monomethylamine salt to the 2,4-D dimethylamine formulations may decrease its vapor potential. However, further studies are required to evaluate the influence of monomethylamine on 2,4-D volatilization. Moreover, while dicamba alone caused greater injury and shorter plant height in soybean than mixture treatments, the opposite was observed when 2,4-D was applied alone. Similar results were demonstrated by Busey et al. (2003) who reported that injury to ornamental and tomato plants was greater when plants were exposed to 2,4-D ester + dicamba ester than to 2,4-D ester alone.

For cotton, no differences were observed among treatments for any of the parameters evaluated in this study. Except for injury to tobacco, no differences among treatments were also observed. As mentioned previously, air temperature and RH can greatly affect herbicide volatility. During the cotton and tobacco experiments, the conditions in the humidome (average mild air temperature ≤21 C and high RH ≥92%) potentially limited the formation of vapor, which may explain why plants responded similarly to the different herbicide treatments. Furthermore, previous research has shown that cotton injury was not different between dicamba DGA and DMA (Bauerle et al. 2015) and between 2,4 choline and 2,4-D amine (Hayden et al. 2013; Sosnoskie et al. 2015).

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Regarding tobacco injury, findings from the present study are in accordance with those reported by Maxwell (2021) that dicamba DMA caused the greatest injury to tobacco plants. Like soybean, treatments with 2,4-D and dicamba alone caused less and more injury, respectively, to tobacco plants compared to treatments with herbicide mixtures. Soybean and tobacco are more sensitive to dicamba than to 2,4-D (Johnson 2011; Johnson et al. 2012; Maxwell 2021; Sciumbato et al. 2004). Consequently, the presence of dicamba in the mixture is expected to increase injury in those crop species. Finally, it is widely reported in the literature that synthetic auxin herbicides at small doses can cause hormesis in crop species (Kniss 2018; Marques et al. 2019; Miller et al. 1962; Sperry et al. 2022). In this study, the biomass reduction of cotton plants exposed to dicamba DMA was negative, which may indicate hormesis from this herbicide.

Practical Implications

This study investigated the response of three major crop species in the southern United States (soybean, cotton, and tobacco) to the vapors of various formulations of the most used synthetic auxin herbicides in the country: 2,4-D and dicamba. The findings of this study were important in elucidating the volatility potential of different formulations of 2,4-D and dicamba under weather conditions that are commonly encountered during the growing season in North Carolina and other southern states, and elucidating the sensitivity of these crops to the vapors of the active ingredients and formulations of these herbicides. In conditions of high average air temperature and RH, soybean will experience less injury when 2,4-D formulations are applied than when dicamba and 2,4-D + dicamba formulations are applied. Furthermore, among the 2,4-D formulations investigated in this study, the lowest risk to soybean injury is anticipated with 2,4-D dual-salt, followed by 2,4-D choline, and then 2,4-D DMA. For cotton, under mild average air temperature and high average air RH, the risk for injury is minimal when either 2,4-D or dicamba are applied, regardless of the formulation. Under similar weather conditions for cotton, dicamba DGA is expected to cause the greatest injury to tobacco, while other dicamba and 2,4-D formulations present a similar risk for injury to this crop. Growers can use this information to select the most suitable herbicide active ingredient and herbicide formulation based on the potential for volatilization and the sensitivity of nearby crops, aiming for satisfactory weed control while mitigating vapor drift that may pose a risk to human, environmental, and crop safety. Ultimately, this knowledge can be extended to other soybean, cotton, and tobacco growing regions with similar weather conditions to those in North Carolina.

Acknowledgments. We gratefully acknowledge financial support from Nufarm, Inc. We also thank the undergraduate assistants who worked in the Pesticide and Trace Element Fate and Behavior Research Group from 2021 to 2023. The authors declare they have no competing interests.

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