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Author for correspondence:
Stephen J. Ippolito, Department of Horticultural Science, North Carolina State University, 2721 Founders Drive, Raleigh, NC 27965. Email: sjippoli@ncsu.edu

Effect of simulated synthetic auxin herbicide sprayer contamination in sweetpotato propagation beds

Thomas M. Batts[1], Levi D. Moore[2], Stephen J. Ippolito[2], Katherine M. Jennings[3] and Stephen C. Smith[2]

[1]County Extension Agent, North Carolina Cooperative Extension—Wilson County Center, Wilson, NC, USA; [2]Graduate Student, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA and [3]Associate Professor, Department of Horticultural Science, North Carolina State University, Raleigh, NC, USA

Abstract

Field studies were conducted to determine the effects of synthetic auxin herbicides at simulated exposure rates applied to 'Covington' sweetpotato propagation beds on the quality of nonrooted stem cuttings (slips). Treatments included diglycolamine salt of dicamba, 2,4-D choline plus nonionic surfactant (NIS), and 2,4-D choline plus glyphosate at 1/10, 1/33, or 1/66 of a 1X application rate (560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D choline, 1,130 g ae ha^{-1} glyphosate) applied at 2 or 4 wk after first slip harvest (WASH). Injury to sweetpotato 2 wk after treatment was greatest when herbicides were applied 2 WASH (21%) compared to 4 WASH (16%). More slip injury was caused by 2,4-D choline than by dicamba, and the addition of glyphosate did not increase injury over 2,4-D choline alone. Two weeks after the second application, sweetpotato slips were cut 2 cm above the soil surface and transplanted into production fields. In 2019, sweetpotato ground coverage 8 wk after transplanting was reduced 37% and 26% by the 1/10X rates of dicamba and 2,4-D choline plus NIS, respectively. Though dicamba caused less injury to propagation beds than 2,4-D choline with or without glyphosate, after transplanting, slips treated with 1/10X dicamba did not recover as quickly as those treated with 2,4-D choline. In 2020, sweetpotato ground coverage was 90% or greater for all treatments. Dicamba applied 2 WASH decreased marketable sweetpotato storage root yield by 59% compared to the nontreated check, whereas treatments including 2,4-D choline reduced marketable yield 22% to 29%. All herbicides applied at 4 WASH reduced marketable yield 31% to 36%. The addition of glyphosate to 2,4-D choline did not increase sweetpotato yield. Results indicate that caution should be taken when deciding whether to transplant sweetpotato slips that are suspected to have been exposed to dicamba or 2,4-D choline.

Introduction

As a result of increases in glyphosate-resistant weed populations, growers are relying on alternative modes of action for successful management (Duke 2015). Because few cases of weed resistance to synthetic auxin herbicides have been reported (Busi et al. 2018), they are used as an alternative to glyphosate for controlling resistant biotypes. In 2019, 2,4-D and dicamba were applied to 35% and 45% of U.S. cotton, respectively (USDA 2020). In 2018, 26% of North Carolina's soybean hectares were dicamba-tolerant (Wechsler et al. 2019). The same year, 1% of non-dicamba-tolerant soybean fields in North Carolina exhibited symptoms attributable to off-target injury from dicamba (Wechsler et al. 2019). Synthetic auxin herbicides are prone to volatilization and subsequent off-target movement (Behrens and Lueschen 1979; Rensburg and Breeze 1990). Thus supplemental application restrictions have been placed on synthetic auxin herbicides in an attempt to prevent off-target movement. In addition, synthetic auxin herbicide residue can remain in spray equipment and injure subsequently treated nontarget crops (Boerboom 2004; Inman et al. 2020). Inman et al. (2020) reported notable concentrations of residual dicamba even after sequential tank rinses.

In 2020, the United States produced 63,500 ha of sweetpotato (USDA-NASS 2020). North Carolina is the largest producer of sweetpotato in the United States, accounting for 67% of the harvested area (USDA-NASS 2020). Sweetpotato is a high-value crop, with a production value of US$726 million and US$375 million in the United States and North Carolina, respectively (USDA-NASS 2020). Sweetpotato is susceptible to injury from synthetic auxin herbicides, with Batts et al. (2020a, 2020b) reporting a reduction in 'Beauregard' sweetpotato yield with increasing rates (1/1,000 to 1/10X) of 2,4-D choline and N,N-Bis(3-aminopropyl)methylamine (BAPMA) and diglycolamine (DGA) salt of dicamba when applied both alone and in combination with glyphosate 30 d after transplanting (DAP). Miller et al. (2020) also observed a decrease in 'Beauregard' sweetpotato yield with increasing rates (1/100 to 1/10X) of 2,4-D choline or DGA salt of dicamba when applied in combination with glyphosate at 30 DAP. Dicamba plus glyphosate applied at 1/100 to 1/33X increased injury by a difference of 11 to 12 percentage points compared to 2,4-D choline plus glyphosate 2 wk after treatment (WAT); however, 1/10X 2,4-D choline plus glyphosate increased injury by a difference of 10% compared to 1/10X dicamba plus glyphosate 2 WAT (Miller et al. 2020).

Sweetpotato production fields in the United States are propagated vegetatively and started from transplanted nonrooted stem cuttings (slips) (Smith et al. 2009). Slips are grown from sweetpotato storage roots buried 6 to 8 cm deep in 1-m-wide beds (propagation beds). After planting, propagation beds are covered with clear polyethylene mulch. After the last spring frost, the polyethylene cover is removed, and sweetpotato shoots emerge. Once slips are approximately 30 cm long, they are cut above the soil line and transplanted into production fields (Thompson et al. 2017). Slips in propagation beds will regrow and are harvested two to three times per season.

Prior research has evaluated the effect of reduced rates of dicamba and 2,4-D choline with or without glyphosate in 'Beauregard' sweetpotato production fields; however, no research has evaluated off-target applications to 'Covington,' the primary sweetpotato cultivar grown in North Carolina (NCDACS 2015). In addition, research is needed to support the decision-making process for transplanting sweetpotato cuttings exposed to synthetic auxin herbicides. Therefore studies were conducted to determine the effect of simulated synthetic auxin herbicide exposure in 'Covington' sweetpotato propagation beds.

Materials and Methods

Propagation Beds

Sweetpotato propagation beds were located on a commercial farm in Springhill, NC, in 2019 (35.638°N, 78.098°W) and 2020 (35.632°N, 78.093°W). Soil was a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult) with pH 6 and <1% organic matter. 'Covington' sweetpotato storage roots were placed in field propagation beds (1 m wide and spaced 1.8 m apart) on March 15, 2019, and March 7, 2020, then covered with 6 to 8 cm of soil. Beds were covered with clear polyethylene mulch, which remained until sweetpotato plants emerged.

The experimental design for each study was a randomized complete block with four replications. Plots were a single row 1.5 m long. Treatments were arranged in a 3 (herbicide) × 3 (herbicide rate) × 2 (application timing) factorial. Herbicide treatments and application rates included DGA salt of dicamba, 2,4-D choline plus 0.25% vol/vol nonionic surfactant (NIS) (Induce®, Helena Agri-Enterprises LLC, Collierville, TN, USA), or 2,4-D choline plus glyphosate at 1/10, 1/33, or 1/66 of a registered rate (Table 1), respectively. The 1X rate was 560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D, or 1,065 g ae ha^{-1} 2,4-D plus 1,130 g ae ha^{-1} glyphosate. In addition, a nontreated check was included for comparison. Treatments were applied 2 or 4 wk after first slip harvest (WASH) using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 200 kPa with a boom equipped with two flat-fan XR 11002VS nozzles (TeeJet® 11002; TeeJet Technologies, Wheaton, IL, USA) spaced 50 cm apart. Slips were approximately 22 and 30 cm in height 2 and 4 WASH, respectively. Data collection included estimates of sweetpotato injury 2 WAT using a scale of 0% (no injury) to 100% (plant death) (Frans et al. 1986). Two weeks after the second application, 20 slips per plot were cut 2 cm above the soil surface and transplanted into sweetpotato production fields.

Production Field

Field sites were located at the Horticultural Crops Research Station, Clinton, NC, in 2019 (35.024°N, 78.279°W) and at a commercial farm in Cross Roads, NC, in 2020 (35.683°N, 78.014°W). Soil at each location was a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudult) with a pH of 6 and <1% organic matter content. Slips were transplanted into raised beds spaced 1 m apart at an in-row spacing of 30 cm. Plots consisted of two rows each 6.1 m long, where the first row was transplanted with nontreated slips and served as a border and the second row was transplanted with slips from an assigned treatment and used for data collection. The study was maintained weed-free with a pretransplant application of flumioxazin, an in-season application of clethodim plus NIS (Table 1), between-row cultivation, and hand roguing, as needed. Data collection included sweetpotato ground coverage 8 wk after transplant. Ground coverage was estimated using a 1 m^2 quadrat with strings arranged in 10 × 10 cm grids. The quadrat was centered over the data row of each plot, then a photograph was taken over top of the quadrat. Images were assessed to count grid intersections containing foliage. The percent reduction in sweetpotato canopy ground cover was calculated as the number of string intersections with foliage divided by the total number of string intersections multiplied by 100 and subtracted from the percent ground coverage of the nontreated check. Sweetpotato storage roots were harvested using a chain digger 119 DAP in 2019 and a turn plow 112 DAP in 2020; hand sorted into canner (>2.5 to 4.4 cm diameter), number (no.) 1 (>4.4 to 8.9 cm), and jumbo (>8.9 cm) grades (USDA 2005); and weighed. Marketable yield was calculated as the sum of no. 1 and jumbo grades.

Statistical Analysis

Data were assessed for homogeneity of variance by examining residual plots. Arcsine square root transformations were required for percent ground cover data. Back-transformed means are presented. Analysis of variance was conducted using PROC GLIMMIX in SAS, version 9.4 (SAS Institute, Cary, NC, USA) with a significance level of $\alpha = 0.05$. Fixed effects included year, herbicide, rate, application timing, and their interactions, whereas replication nested within year was considered a random effect. Rate responses could not be appropriately described using regression analysis; thus all means were separated using Tukey's honestly significant difference (HSD) at a significance level of $\alpha = 0.05$.

Results and Discussion

Propagation Bed Injury

Injury to sweetpotato slips appeared as epinasty, leaf cupping, stem swelling and cracking, and stunting. A significant ($P < 0.0001$) herbicide × rate interaction was present for sweetpotato propagation bed injury. No other significant interactions were present. Sweetpotato slip injury 2 WAT was slightly greater ($P < 0.0001$) when herbicides were applied 2 (21%) compared to 4 WASH (16%) (data not shown). Treatments including 1/10X 2,4-D choline caused the greatest injury to propagation bed plants (37% and 39%), and the addition of glyphosate to 2,4-D did not increase injury at any rate applied (Table 2). These data differ from injury observed in previous studies in production fields. Batts et al.

Table 1. Herbicides and sources used for the studies.

Active ingredient	Trade name	Rate	Manufacturer	City, state	Website
		g ai/ae ha^{-1}			
Clethodim[a]	Select Max®	135	Valent USA Corp.	Walnut Creek, CA	www.valent.com
Dicamba	XtendiMax®	9, 18, 56	Bayer CropScience	St. Louis, MO	www.cropscience.bayer.com
Flumioxazin	Valor® SX	107	Valent USA Corp.	Walnut Creek, CA	www.valent.com
2,4-D[a]	Enlist One®	17, 33, 106	Corteva Agriscience™	Wilmington, DE	www.corteva.com
2,4-D plus glyphosate	Enlist Duo®	17 + 18, 33 + 36, 106 + 113	Corteva Agriscience™	Wilmington, DE	www.corteva.com

[a]Nonionic surfactant (Induce®) was included at 0.25% vol/vol.

Table 2. Sweetpotato injury 2 wk after treatment as affected by dicamba, 2,4-D, and 2,4-D plus glyphosate applied at simulated exposure rates to sweetpotato in propagation beds in North Carolina in 2019 and 2020.[a],[b],[c]

Herbicide	Rate[d]	Sweetpotato injury[e]
	g ae ha^{-1}	%
Dicamba	1/66X	7 d
	1/33X	13 bcd
	1/10X	18 b
2,4-D[f]	1/66X	11 cd
	1/33X	16 bc
	1/10X	37 a
2,4-D plus glyphosate	1/66X	11 cd
	1/33X	16 bc
	1/10X	39 a

[a]Injury was characterized as epinasty, leaf cupping, and stem swelling and cracking.
[b]Data were pooled across years and application timings (2 or 4 wk after the first slip harvest).
[c]Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference, $\alpha = 0.05$.
[d]The 1X rate was 560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D, or 1,065 g ae ha^{-1} 2,4-D plus 1,130 g ae ha^{-1} glyphosate.
[e]Rating scale: 0%, no treatment effect; 100%, plant death.
[f]Nonionic surfactant (0.25% vol/vol) was included.

Table 3. Effect of application timing and rate of dicamba, 2,4-D, and 2,4-D plus glyphosate applied to sweetpotato propagation beds on sweetpotato ground coverage 8 wk after transplanting to production fields in Clinton and Cross Roads, North Carolina, 2019 and 2020.[a],[b],[c]

Application timing	Rate[d]	Reduction in ground coverage
	g ae ha^{-1}	% of nontreated
2 WASH	1/66X	4 b
	1/33X	11 a
	1/10X	11 a
4 WASH	1/66X	0 b
	1/33X	3 b
	1/10X	16 a

[a]Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference, $\alpha = 0.05$.
[b]Data were pooled across years and herbicide.
[c]Abbreviation: WASH, weeks after first slip harvest.
[d]The 1X rate was 560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D, or 1,065 g ae ha^{-1} 2,4-D plus 1,130 g ae ha^{-1} glyphosate.

(2020a) reported that the addition of glyphosate to 2,4-D at the 1/10X rate increased 'Beauregard' sweetpotato injury 2 WAT by 12 percentage points compared to 2,4-D alone when applied in production fields; however, NIS was not included in treatments. Injury in the present study was less than 64% or 74% injury 2 WAT reported by Miller et al. (2020) from 1/10X 2,4-D choline plus glyphosate or dicamba plus glyphosate, respectively, applied in sweetpotato production fields.

Production Field

Sweetpotato Ground Coverage

Analysis indicated a significant application timing × rate interaction ($P = 0.01$); no other interactions, including application timing, were significant ($P > 0.05$). At the 1/66 (4% and 3%) and 1/10X (11% and 16%) rates, application timing did not have a significant effect on ground coverage (Table 3); however, the 1/33X rate reduced sweetpotato ground coverage more when applied 2 WASH compared to 4 WASH (11 vs 3%). The year × herbicide × rate interaction was significant ($P = 0.03$); therefore the herbicide × rate interaction was assessed by year. The 1/66 and 1/33X rates cased 12% or less reduction in sweetpotato ground coverage for all herbicides (Table 4). In 2019, 1/10X dicamba and 2,4-D choline plus NIS reduced ground coverage 37% and 26%, respectively. The addition of glyphosate to 2,4-D choline did not reduce ground coverage compared to 2,4-D choline plus NIS. In 2020, sweetpotato ground coverage was 90% or greater for all treatments. Though 1/10X dicamba caused less injury to propagation beds than 1/10X 2,4-D or 2,4-D choline plus glyphosate, after transplanting, slips that were treated with 1/10X dicamba recovered as slowly as or slower than those treated with 2,4-D. However, Miller et al. (2020) reported that 'Beauregard' sweetpotato injury rates from 1/10X and 1/33X rates of 2,4-D choline plus glyphosate and dicamba plus glyphosate applied in production fields were similar 5 WAT.

Yield

Only application timing × herbicide ($P \leq 0.004$) and application timing × rate ($P \leq 0.001$) interactions were significant for marketable and no. 1 yield data. No significant effects or interactions were present for jumbo-grade yield data. In 2019 and 2020, marketable yields from the nontreated check were 30,327 and 46,923 kg ha^{-1}, respectively; no. 1 yield was 22,127 and 40,679 kg ha^{-1}, respectively. Dicamba applied 2 WASH decreased marketable yield by 59%, whereas treatments including 2,4-D choline decreased marketable yield 22% to 29% (Table 5). All herbicides applied 4 WASH reduced marketable yield 31% to 36%. The addition of glyphosate to 2,4-D choline did not affect sweetpotato yield compared to 2,4-D choline plus NIS. All herbicide rates applied 2 WASH reduced marketable yield 33% to 39%. At 4 WASH, increasing the application rate from 1/66X to 1/10X decreased marketable yield by 36%. In previous research, dicamba plus glyphosate or 2,4-D choline plus glyphosate reduced total 'Beauregard' sweetpotato yield 0% to 66% from 1/66X to 1/10X rates, respectively, when applied in sweetpotato production fields (Miller et al. 2020). All treatments in the present study were applied after the initial slip harvest;

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Table 4. Effect of dicamba, 2,4-D, and 2,4-D plus glyphosate applied at simulated exposure rates to sweetpotato propagation beds on sweetpotato ground coverage 8 wk after transplanting to production fields in North Carolina.[a,b]

		Reduction in ground coverage	
Herbicide	Rate[c]	2019	2020
	g ae ha^{-1}	——— % of nontreated ———	
Dicamba	1/66X	6 bc	5
	1/33X	6 bc	10
	1/10X	37 a	4
2,4-D[d]	1/66X	0 c	5
	1/33X	12 bc	0
	1/10X	26 ab	0
2,4-D plus glyphosate	1/66X	9 bc	2
	1/33X	3 c	5
	1/10X	12 bc	1

[a]Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference, α = 0.05. Means within a column not followed by a letter are not significantly different according to a nonsignificant F statistic ($P > 0.05$).
[b]Data were pooled across application timings (2 or 4 wk after the first slip harvest).
[c]The 1X rate was 560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D, or 1,065 g ae ha^{-1} 2,4-D plus 1,130 g ae ha^{-1} glyphosate.
[d]Nonionic surfactant (0.25% vol/vol) was included.

Table 5. Effect of dicamba, 2,4-D, and 2,4-D plus glyphosate applied to sweetpotato propagation beds at simulated exposure rates on production field storage root yield in Clinton and Cross Roads, North Carolina, 2019 and 2020.[a,b,c,d]

		Sweetpotato yield loss	
Application timing[e,f]	Herbicide	No. 1	Marketable
		— % of nontreated —	
2 WASH	Dicamba	65 a	59 a
	2,4-D[g]	37 b	29 bc
	2,4-D plus glyphosate	35 b	22 c
4 WASH	Dicamba	41 b	36 b
	2,4-D[g]	38 b	33 bc
	2,4-D plus glyphosate	40 b	31 bc
Application timing[h]	Rate[i]		
	g ae ha^{-1}		
2 WASH	1/66X	43 ab	39 ab
	1/33X	45 ab	33 b
	1/10X	49 ab	37 b
4 WASH	1/66X	21 c	16 c
	1/33X	37 bc	32 b
	1/10X	62 a	52 a

[a]Sweetpotato storage roots were hand graded into canner (>2.5 to 4.4 cm diameter), number (no.) 1 (>4.4 to 8.9 cm), jumbo (>8.9 cm), and marketable (sum of no. 1 and jumbo grades) yield.
[b]Means within a column and dependent variable followed by the same letter are not significantly different according to Tukey's honestly significant difference, α = 0.05.
[c]Data were pooled across application rates.
[d]Abbreviation: WASH, weeks after first slip harvest.
[e]Data were pooled across years.
[f]Treatments were applied 2 or 4 wk after first slip harvest.
[g]Nonionic surfactant (0.25% vol/vol) was included with the 2,4-D treatment.
[h]Data were pooled across herbicides.
[i]The 1X rate was 560 g ae ha^{-1} dicamba, 1,065 g ae ha^{-1} 2,4-D, or 1,065 g ae ha^{-1} 2,4-D plus 1,130 g ae ha^{-1} glyphosate.

however, sweetpotato injury from auxin exposure in newly emerged propagation beds may differ. Thus additional research should evaluate the effects of auxin exposure at various propagation bed growth stages.

The rates used in the present study ranged from 1/66X to 1/10X; however, herbicide drift from an adjacent field is generally expected to occur at rates less than 1/100X (Egan et al. 2014). In addition, carrier volumes are much lower in drift situations and should also be reduced (Banks and Schroeder 2002). Inman et al. (2020) reported that insufficient sprayer tank cleanout can leave 19% (approximately 1/5X rate) or 4% (1/25X rate) of the initial dicamba concentration from one or two tank rinses, respectively. Thus the present study gives better insight into nontarget applications from tank contamination events rather than drift events. Sweetpotato slips treated with a 1/66X rate resulted in 11% or less injury in the propagation bed but still decreased marketable yield by ≥16%. Therefore caution should be taken when deciding to transplant sweetpotato slips that are suspected to have been exposed to synthetic auxin herbicides.

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