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Tolerance of southern highbush blueberry to 2,4-D choline postemergence-directed

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Research Article

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Abstract

Field studies were conducted on southern highbush blueberry in Elizabethtown and Rocky Point, NC, in 2019, 2020, and 2021 to determine tolerance to 2,4-D choline as a postemergence-directed application. In separate trials for younger and older bearing blueberry bushes, both 2,4-D choline rates and application timing were evaluated. Treatments included 2,4-D choline at 0, 0.53, 1.06, 1.60, and 2.13 kg ae ha⁻¹ applied alone in winter during dormancy, and sequential treatments at 0.53 kg ae ha⁻¹ followed by (fb) 0.53, 1.06 fb 1.06, 1.6 fb 1.6, or 2.13 fb 2.13 kg ae ha⁻¹. The first application of the sequential treatments was applied in winter followed by another application in spring during early green fruit. Injury to blueberry from 2,4-D choline treatments was not observed for either maturity stage, and fruit yield was not affected by any of the treatments. Differences among treatments were not observed for fruit soluble solid content (SSC) in older bushes, or for fruit pH, SSC, and titratable acidity (TA) in younger bushes. In older bushes, fruit pH and TA had rate-by-timing interactions, and TA had a farm-year interaction with differences at Rocky Point in 2019 and Elizabethtown in 2020, but biologically no pattern was observed from the treatments.

Introduction

In the United States in 2019, over 41,500 ha of blueberry (*Vaccinium* spp.) valued at \$908 million was harvested, with Georgia and Michigan ranked first and second, respectively (USDA 2020). North Carolina ranked sixth in production, with blueberry fruit harvested on 3,500 ha with a \$60.8 million value in 2019 (NCDA&CS 2020; USDA 2020). Weeds are managed in blueberry using herbicides, hand weeding, polyethylene mulch at establishment, and natural mulch (pine bark, sawdust) on the bed. Hand weeding can be effective but expensive, with annual estimates in North Carolina of 12.4 h of labor ha⁻¹ at a cost of US\$160 ha⁻¹ (Safley et al. 2006; USDOL 2021). Mulches are not widely used; polyethylene mulch was only used on 19% of farms in North Carolina, and natural mulch was used on 63% of farms ($N = 16$) (unpublished 2021 survey). Of farms using natural mulch, 90% produce blueberries on 2.5 ha or less ($N = 10$) (unpublished 2021 survey). Herbicides are a valuable tool, with 16 herbicide options for preemergence and seven herbicide options for nonselective postemergence (Mitchem et al. 2021) weed control, but growers that use herbicides mainly use flumioxazin preemergence (57%), glyphosate (57%), or glufosinate (43%) postemergence-directed ($N = 7$) (unpublished 2021 survey). The overuse of a few herbicides could lead to herbicide resistance in weed populations, resulting in a reduction in the number of effective herbicides available for growers to use (Vencill et al. 2012). It is important to evaluate herbicides for use in blueberry and identify any herbicides having potential for use in the crop, as such evaluation may increase weed management options and limit herbicide resistance.

In 2013, Meyers et al. evaluated preemergence and postemergence herbicides in blueberry, but the only selective postemergence herbicide was halosulfuron. This study considered the effect of the herbicides on fruit yield, but not fruit quality parameters such as pH, titratable acidity (TA), and soluble solid content (SSC).

A potentially effective herbicide for blueberry production is 2,4-D, a synthetic auxin in the phenoxy-carboxylic acid family and WSSA Group 4 (Shaner 2014). Mimicking indole acetic acid, 2,4-D disrupts nucleic acid metabolism and processes in the cell wall (Shaner 2014). When 2,4-D is applied as a postemergence herbicide, it affects cell division and growth in meristematic regions (Shaner 2014). The 2,4-D choline salt formulation has lower volatility than the amine salt because of higher stability and less disassociation from 2,4-D acid, decreasing the

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Table 1. Year, location, cultivar, crop age, treatment application dates, and harvest dates for studies evaluating effect of 2,4-D postemergence-directed on southern highbush blueberry, 2019–2021.

Year	Location and GPS coordinates	Cultivar	Crop age	Average bush height	Treatment application dates ^a		Harvest date
					Winter	Spring	
2019	Elizabethtown, NC (34.6601°N, 78.4866°W) Rocky Point, NC (34.4198°N, 78.0406°W)	Legacy	8 yr	152 cm	Jan 28, 2019	Apr 22, 2019	May 15, 2019
		New Hanover	11	– ^b	Feb 4, 2019	Apr 22, 2019	May 23, 2019
2020	Elizabethtown, NC (34.6617°N, 78.4870°W) Rocky Point, NC (34.4317°N, 78.0482°W) Elizabethtown, NC (34.6604°N, 78.4880°W) Rocky Point, NC (34.4168°N, 78.0414°W)	San Joaquin	8	147	Jan 6, 2020	Apr 14, 2020	May 18, 2020
		New Hanover	7	165	Jan 6, 2020	Apr 14, 2020	May 18, 2020
		Star	4	92	Jan 6, 2020	Apr 14, 2020	May 11, 2020
		Suziblue	4	90	Jan 6, 2020	Apr 14, 2020	May 12, 2020
2021	Elizabethtown, NC (34.6572°N, 78.4808°W) Rocky Point, NC (34.4214°N, 78.0387°W)	O'Neal	3	125	Jan 14, 2021	Apr 6, 2021	– ^c
		Suziblue	5	113	Jan 14, 2021	Apr 6, 2021	May 17, 2021

^aWinter application included single plus first sequential treatments, and spring applications included second sequential treatments.

^bBlueberry bush height not recorded in Rocky Point, NC in 2019.

^cBlueberry fruit were not harvested in Elizabethtown, NC, in 2021 because of a hailstorm.

vapor movement potential (Anonymous 2012; Peterson et al. 2016). This should reduce the potential for volatility from the application site onto the blueberry bushes, lowering any potential off-target injury effects. Many annual and perennial broadleaf weeds common to blueberry production are effectively controlled by 2,4-D, including annual morningglory (*Ipomoea* spp.), common lambsquarters (*Chenopodium album* L.), curly dock (*Rumex crispus* L.), field bindweed (*Convolvulus arvensis* L.), Canada goldenrod (*Solidago canadensis* L.), horseweed (*Erigeron canadensis* L.), and vetch species (*Vicia* spp.) (Anonymous 2021).

The 2,4-D choline formulation was recently registered for use in bearing blueberry (Anonymous 2021). The objective of this study was to determine tolerance of younger and older bearing blueberry bushes to 2,4-D choline postemergence-directed.

Materials and Methods

Field studies were conducted at two commercial blueberry farms in Elizabethtown and Rocky Point, NC, in 2019, 2020, and 2021. One study looked at older (>5 yr) fruit-bearing southern highbush blueberry bushes, and a second study looked at younger (≤5 yr) fruit-bearing southern highbush blueberry bushes (Table 1). Soils were primarily a sand or fine sand, with pH between 3.9 and 4.9, and organic matter ranging from 0.7% to 8.1% (Table 2). Blueberries at the two study sites were maintained weed-free and managed by the commercial blueberry farms using best management practices (Burrack 2021).

The experimental design was a two-by-four factorial with 2,4-D choline application timing and rate as main factors plus a nontreated control in a randomized complete block with treatments replicated four times. Plots consisted of a single planted row 1.5 m wide by 2.7 m long containing three blueberry bushes spaced 0.9 m apart. Blueberry rows were spaced 2.7 m apart. Treatments included 2,4-D choline (Embed Extra; Corteva Agriscience, Indianapolis, IN) at 0.53, 1.06, 1.6, and 2.13 kg ae ha⁻¹ applied postemergence-directed as single and sequential treatments. Treatments (single, or first application in the sequential treatments) were applied pre-budbreak in winter (January or February), whereas

Table 2. Soil characteristics by site for studies evaluating effect of 2,4-D postemergence-directed to southern highbush blueberry in North Carolina, 2019–2021.

Study site ^a	Series	Soil characteristics				
		pH	OM ^b	Sand	Clay	Silt
E19	Leon sand (Sandy, siliceous, thermic Aeric Alaquods)	4.9	1.4	92	2.2	5.6
RP19	Murville muck (Sandy, siliceous, thermic Umbric Endoaquods)	3.9	8.1	84	2.2	13.6
E20a	Leon sand (Sandy, siliceous, thermic Aeric Alaquods)	4.7	1.7	96.4	1.6	2
RP20a	Autryville fine sand (Loamy, siliceous, subactive, thermic Arenic Paleudults)	4.3	0.7	95.2	1.2	3.6
E20b	Centenary sand (Sandy, siliceous, thermic Entic Grossarenic Alorthods)	4.8	1.4	89.6	4.8	5.6
RP20b	Kureb fine sand (Thermic, uncoated Spodic Quartzipsamments)	4.2	1.4	90.4	5.6	4
E21	Leon sand (Sandy, siliceous, thermic Aeric Alaquods)	4.6	1.7	93.2	3.2	3.6
RP21	Baymeade fine sand (Loamy, siliceous, semiactive, thermic Arenic Hapludults)	4.1	1.23	88	7.6	4.4

^aStudy site abbreviations [location, year, cultivar (if needed)]: E19, Elizabethtown 2019; RP19, Rocky Point 2019; E20a, Elizabethtown 2020 'San Joaquin'; RP20a, Rocky Point 2020 'New Hanover'; E20b, Elizabethtown 2020 'Star'; RP20b, Rocky Point 2020 'Suziblue'; E21, Elizabethtown 2021; RP21, Rocky Point 2021.

^bAbbreviation: OM, organic matter.

the second application in the sequential treatment was applied during early green fruit in spring (April). Treatments were directed toward the base of the blueberry bush on both sides of the planting row, no higher than 15 cm above the soil line, such that overlap occurred, avoiding contact with foliage when possible. Treatments were made in a 30-cm band using a CO₂-pressurized backpack sprayer calibrated to deliver 187 L ha⁻¹ at 138 kPa with two TeeJet 8003 VS nozzles (TeeJet Technologies, Springfield, IL).



Figure 1. (A) Older blueberry bushes 2 wk after January treatments in Rocky Point, NC, in 2020. (B) Younger blueberry bushes 2 wk after April treatments in Elizabethtown, NC, in 2021.

Data collected included visible crop injury characterized by stunting or leaf chlorosis and necrosis rated on a scale of 0 (no injury) to 100% (crop death) at 1, 2, 4, and 8 wk after treatment (WAT) (both application timings). New foliage was absent on blueberry bushes 1, 2, 4, and 8 wk after the first application; however, new foliage was present 1, 2, 4, and 8 wk after the second application (Figure 1).

All berries were harvested at one time from the center bush of each plot when commercial crews began harvesting the specific cultivar. In 2021, a hailstorm caused total crop loss at the Elizabethtown site, eliminating the yield and fruit quality data

for that site. Harvest occurred in mid-May for all studies. Total berry weight was taken per plot using an FG-150KBM kg scale (A&D Company Limited, Tokyo, Japan), then berries were sorted by marketable (mature, firm blue berries) and unmarketable (immature, green or overripe, soft blueberries) using a WECO BerryTek sorter (Woodside Electronics Corp., Woodland, CA) from all studies except the younger bush trials in 2020. Due to COVID-19 restrictions in place at the time of harvest in 2020, the fruit harvested from the younger bush trial were hand sorted by marketable and unmarketable. Average berry weight was calculated from 10 samples of marketable and 10 samples

of unmarketable berries, with each sample containing 100 berries, which were randomly collected across the plots. Estimated marketable berry weight was determined by dividing the mean marketable berry weight by the mean unmarketable berry weight and multiplying by total unmarketable berry weight per plot. Estimated total yield per plot was calculated by adding estimated marketable berry weight to marketable berry (Equation 1) (Aldridge et al. 2019; Coneybeer-Roberts et al. 2016; Meyers et al. 2016).

$$\left[\frac{\text{Mean marketable berry weight}}{\text{Mean unmarketable berry weight}} \right] \times \text{Total unmarketable berry weight plot}^{-1} + \text{Total marketable berry weight plot}^{-1} \quad [1]$$

One hundred marketable berry samples were collected from each plot, except in 2020 when 50 berries were collected from the younger bush study in Elizabethtown due to limited yield. Samples were weighed and placed in a -20 C freezer and held until fruit were analyzed. Frozen blueberry samples were thawed to room temperature, then homogenized by hand crushing, and juice extracted. Each homogenized sample was analyzed for pH, TA [percent citric acid equivalents (v/v)], and total SSC. The pH of each fruit sample was measured using a PC800 pH meter (Apera Instruments, Columbus, OH) standardized to pH 4 and 7. SSC and TA were determined by the PAL-BX|ACID F5 pocket Brix-acidity meter (Atago Co., Ltd., Bellevue, WA), using setting 5 for blueberry.

Response variables of crop injury, yield, and fruit quality (SSC, TA, and pH) were subjected to ANOVA and analyzed in SAS PROC MIXED (SAS 9.4; SAS Institute, Cary, NC). Studies were considered as specific combinations of location (farm) and year (farm-year). Herbicide application timings, rates, and farm-year were considered fixed effects, and replication and replication within farm-year were considered random effects. Means were separated by Fisher's protected LSD at a significance level of 0.05. The nontreated control was not included in crop injury analyses, and older bush TA was calculated as percent of the nontreated.

Results and Discussion

No visible crop injury was observed in any study with either the older or younger bushes. There was no significant farm-year interaction with yield, so data were combined across years and location for each maturity stage. No differences were observed in yield for either the older or the younger bushes (Table 3). Similar results of no effect on yield were observed in strawberry (*Fragaria × ananassa* Duch.) when 2,4-D was applied in the row middles of plasticulture production (Sims et al. 2022).

Data were combined across years and locations for fruit quality (pH, TA, SSC) in the younger bush trials and pH and SSC in the older bush trials, because there were no significant farm-year interactions. No differences were observed in any fruit quality parameter in the younger bush trials or in SSC in the older bush trials (Table 3), which were similar to findings with 2,4-D in strawberry (K Sims, personal communication). There was a significant rate-by-timing interaction for fruit pH of older bushes ($P = 0.014$); however, biologically the range in pH of the older bushes (3.23 to 3.32) is not significant in commercial production, and difference may have been due to variance in ripeness of fruit at

Table 3. Effect of 2,4-D choline postemergence-directed in blueberry on estimated total yield of older and younger bushes, fruit pH, titratable acidity (TA), and soluble solid content (SSC) of younger bushes, and on SSC of fruit of older bushes, combined across years and locations in Elizabethtown and Rocky Point, NC, in 2019–2021.

Rate		Yield		Fruit quality			
Winter ^a	Spring ^b	Older ^c	Younger ^d	Older	Younger		
				SSC ^e	pH	TA ^f	SSC
—kg ae ha ⁻¹ —		—kg ha ⁻¹ —					
Nontreated		13,031	16,538	12.2	3.45	0.59	13.7
0.53		14,147	18,012	12.0	3.52	0.55	14.0
1.06		13,469	19,925	12.2	3.47	0.27	13.7
1.6		15,302	15,860	12.2	3.51	0.55	13.9
2.13		12,632	14,904	12.1	3.48	0.57	13.9
0.53	0.53	12,354	16,339	12.2	3.45	0.60	14.1
1.06	1.06	14,167	18,172	12.3	3.55	0.54	14.4
1.6	1.6	12,792	18,530	12.5	3.48	0.63	13.8
2.13	2.13	14,745	13,350	12.3	3.58	0.58	14.0
P value		NS ^g	NS	NS	NS	NS	NS

^aWinter applications were made in January or February.

^bSpring applications were made in April, when bushes had early green fruit.

^cOlder bushes were >5 yr old.

^dYounger bushes were ≤5 yr old.

^eSSC is expressed in °Brix.

^fTA is measured in percent citric acid equivalents (v/v).

^gAbbreviation: NS, not significant.

Table 4. Effect of 2,4-D choline postemergence-directed to blueberry on fruit titratable acidity (TA) of older bushes, separated by year and location, in Elizabethtown and Rocky Point, NC, in 2019–2020 as a percent of the nontreated.^{a,b}

Timing ^c (T)	Rate (R)	Titratable acidity ^d			
		2019		2020	
		Elizabethtown	Rocky Point	Elizabethtown	Rocky Point
		—% of nontreated—			
Winter	0.53	88	136	102 a	93
	1.06	76	126	83 b	102
	1.6	88	128	91 ab	94
	2.13	97	129	90 ab	101
	P value	0.0972	0.7404	0.0359	0.1589
Spring	0.53	80	112 a	85	95
	1.06	101	127 ab	95	88
	1.6	86	114 a	93	90
	2.13	91	158 b	96	101
	P value	0.5464	0.0390	0.2161	0.2274
T × R	P value	0.1632	0.0238	0.0107	0.1972

^aMeans within a column of the same timing followed by the same letter are not different according to Fisher's protected LSD ($\alpha = 0.05$).

^bTA means from nontreated treatments were 1.37, 0.64, 1.10, and 0.41 from Elizabethtown 2019, Rocky Point 2019, Elizabethtown 2020, and Rocky Point 2020, respectively.

^cWinter applications were made in January or February; and spring applications were made in April when bushes had early green fruit.

^dTA is measured in percent citric acid equivalents (v/v).

harvest (P Perkins-Veazie, personal communication) (data not presented).

Blueberry fruit TA from the older bushes had a three-way interaction between rate, timing, and farm-year, so data were run separately by farm-year. There was no difference in TA at Elizabethtown in 2019 or Rocky Point in 2020, but statistical differences were observed at Rocky Point in 2019 and Elizabethtown in 2020 (Table 4). In Rocky Point in 2019, no

differences were observed in TA between single applications, but TA of fruit in the highest rate of the sequential treatment (2.13 fb 2.13 kg ae ha⁻¹) was different from the sequential treatments 0.56 fb 0.56 kg ae ha⁻¹ and 1.06 fb 1.06 kg ae ha⁻¹. In Elizabethtown the opposite was observed, where differences were seen in the single application but not in the sequential application. The lowest rate of 2,4-D choline (0.56 kg ae ha⁻¹) was different from 1.06 kg ae ha⁻¹ but not from 1.60 and 2.13 kg ae ha⁻¹. As with the older bush fruit pH, these statistical differences do not warrant a biological difference.

These results indicate that 2,4-D choline directed to the base of younger and older bearing blueberry bushes does not affect crop growth, fruit yield, or fruit quality when applied sequentially in winter and spring. There is limited literature on both multi-year studies in perennial fruit crops, and the implications of using 2,4-D choline on crop tolerance and fruit quality. Dintelmann et al. (2019) considered tolerance of apple (*Malus domestica* Borkh) and peach (*Prunus persica* L.) to 2,4-D choline, but this research was conducted over a single year and did not include fruit quality. Future research should include a multi-year study looking at the effects of 2,4-D choline when applied in sequential years on growth, fruit yield, and fruit quality.

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