Evaluation of plant growth regulators to reduce biennial bearing of two cider apple cultivars in Vermont, U.S.A.

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ABSTRACT

Crop load management is a critical component of commercial apple production. For commonly-grown dessert cultivars, removal of a portion of fruit each season via chemical thinning helps to maintain fruit size, quality, and annual bearing characteristics. Commonly-used thinning protocols in northeastern U.S.A. orchards include application of carbaryl at petal fall alone or in combination with other plant growth regulators (PGRs). European-origin cider apple cultivars typically do not respond similarly to chemical thinning programs used in production of dessert fruit. In the past two decades, application of PGRs at a later timing in midsummer has increasingly been used to increase fruit bud development for the following year on certain dessert apple cultivars with pronounced biennial bearing tendencies. In 2016 and 2017, multiple PGR programs were applied to 'Kingston Black' and 'Ellis Bitter' trees in a commercial orchard in Vermont, U.S.A. Trees were evaluated for crop yield and juice quality in each season. During the two years of the study, both cultivars exhibited strong biennial production habit. Within each year, PGR treatments had inconsistent effects on crop yield, but no effects of practical significance on juice quality. Despite a lack of PGR effects on substantially reducing biennialism, interactions of specific treatments and cultivars may inform continued research on this topic.

Keywords: *crop load, thinning, 'Kingston Black', 'Ellis Bitter', juice quality, cider apple cultivars*

INTRODUCTION

Fermented cider production has increased dramatically in the U.S. in recent years with an annualized growth rate of 50% between 2009 and 2014 with revenues totaling $292.5 million in 2014 (Petrillo, 2014). In Vermont, orchards are being managed specifically to provide fruit to this expanding market, but prices paid for processing fruit remain below those for fresh market apples (Becot, et al., 2018). Cider producers purchased over 200,000 bushels of Vermont apples, primarily traditional dessert cultivars (e.g. 'McIntosh', 'Cortland'), in 2014 at an average price of $5.75 per bushel. That is only 30% of the price received for fresh market apples (Becot, et al., 2016; NASS, 2016). Growers have begun planting specialty cider cultivars with unique sugar, acid, and tannin profiles suited to making high-quality cider. Cideries seeking these cultivars are willing to pay $20 or more per bushel, making them competitive with dessert fruit production but production of hard cider specific varieties is presently limited (Becot, et al., 2016).

Traditionally, application of carbaryl with or without other plant growth regulators (PGRs) at petal fall (post-bloom) and soon thereafter is used for fruit thinning to increase fruit size and bud development for the following year (Byers, 2003). European bittersweet and similar cider cultivars as a class generally respond poorly to traditional chemical thinning programs used for dessert fruit, which makes cropload management difficult (Merwin et. al., 2008). As a result, many cider cultivars have strong biennial cropping tendencies which reduces farm profitability. Recent research on the effects of PGRs applied to dessert cultivars in midsummer (after the traditional window for apple thinning) suggests that floral bud formation in biennial cultivars may be achieved with the compounds NAA and/or ethephon (Duyvelshoff and Cline, 2013; McArtney, et al., 2013; McArtney, et

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al., 2007). PGRs used for thinning also affect fruit quality and harvest characteristics when applied closer to harvest. For example, ethephon may advance fruit maturity and lead to pre-harvest drop (McArtney, et al., 2007; Stover, et al., 2003), while naphthalene acetic acid (NAA) may delay maturity (Marini, et al., 1993; Yuan and Carbaugh, 2007). In this trial, ethephon and NAA with and without carbaryl were tested on two cider apples cultivars in two successive growing seasons to assess effects on crop yield, fruit quality, and juice characteristics.

MATERIALS AND METHODS

Table 1. Experimental treatments

	U.S. label rate/acre	Concentration (per liter)	Application timing			
			Petal Fall	6WAPF	8WAPF	10WAPF
NTC	-	-	-	-	-	-
Carbaryl	16 fl oz	1.25 ml	x	-	-	-
NAA	3 oz	0.23 g	-	x	x	x
Carbaryl	16 fl oz	1.25 ml	x	-	-	-
NAA	3 oz	0.23 g	-	x	x	x
Ethephon	8 oz	0.62 ml	-	x	x	x
Carbaryl	16 fl oz	1.25 ml	x	-	-	-
Ethephon	8 oz	0.62 ml	-	x	x	x

…

Research was conducted in a commercial orchard in Addison County, VT (Köppen-Geiger classification Dfb, USDA cold hardiness zone 4b). Soil is a tile-drained Vergennes clay. Treated trees included two specialty cider cultivars with known biennial tendencies, 'Ellis Bitter' and 'Kingston Black', on M.9/MM.111 interstem rootstocks planted in 2012 at 3.5 x 4.5 m spacing and trained to freestanding central leader system. Trees had not yet filled their allotted space and were not touching which allowed for treatment application without drift to adjoining replicates. The orchard was managed for disease, insect pests, and tree nutrition parameters following the grower's standard protocols. Trees were planted in solid rows of each cultivar, and no PGRs were applied by the grower during the study. All experimental treatments were applied by project technical personnel using a hydraulic handgun sprayer (SHURflo Model #2088-313-445 , Cypress, CA) calibrated at 2.75 bar, 13.6 l/minute and using standard protocols, including non-treated guard trees between each treatment (Cromwell, et al., 2011).

Three PGRs were evaluated in the study: Carbaryl 4L at 0.58 L * ha^{-1} (Drexel Chemical Company, Memphis, TN,); Fruitone N at 210 g * ha^{-1} (1-Naphthaleneacetic Acid, Sodium Salt, AMVAC Chemical Corp, Los Angeles, CA); and Ethephon at 0.29 L * ha^{-1} (2-chloroelhyl) phosphonic acid) (Ethrel, Bayer Crop Science, Calgary, AB). Treatments were applied to single tree replicates in a completely randomized design and repeated on the same trees over two consecutive seasons, and were selected to assess effects of carbaryl at petal fall, midsummer PGR treatments, and combinations of the two:

Data collected included total crop yield (number and kg fruit / tree) and percent of fruit dropped prior to harvest. Harvest was timed based on preliminary starch index readings (Blanpied and Silsby, 1992) from fruit collected from guard trees and the grower's scheduled harvest. At harvest, 10-fruit samples were collected per replicate and stored in regular air storage at 2-3°C until lab evaluation which occurred within 72 hours. Sample fruit were processed and juice quality was

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analyzed for parameters including starch index, flesh firmness, pH, titratable acidity, total phenolics, and soluble solids using standard protocols (Bradshaw, et al., 2013; Miles and King, 2014). Analysis of variance (PROC GLM, SAS version 9.2, Cary, NC) was performed separately for each year and cultivar using Tukey's adjustment for multiple comparisons if the overall F-test was significant at α=0.05.

RESULTS AND DISCUSSION

Overall, there was little effect from PGR application on crop yield parameters (Table 2). Both cultivars exhibited strong biennial bearing tendencies with substantially greater yield in 2016 compared to little yield in 2017. In the latter year, many trees for both cultivars bore no fruit, and the very low crop load in that year likely affected all subsequent measurements of fruit and juice quality because of uneven ripening and smaller aggregate samples used for calculation of mean values. Thinning effect in the first year was inconsistent across the two cultivars. For 'Kingston Black' no effect was found, although the NAA treatment had approximately double the fruit number (but not kg yield) as all other treatments. In 2017, the ethephon treatment had greater yield than each of the treatments which included carbaryl. This suggests that 'Kingston Black' may respond to summer ethephon treatments for improved return bloom, but that carbaryl is ineffective as a fruit thinner on that cultivar. On 'Ellis Bitter' in 2016, NAA-treated trees had greater fruit number than carbaryl-only treated trees, and there was a trend toward reduced fruit number and kg yield on carbaryl and ethephon-treated trees compared to the NAA treatment and the untreated control. In 2017, crop yield for 'Ellis Bitter' was not different among treatments, but a trend toward increased fruit on carbaryl-treated trees suggests that more effective thinning the prior year may have increased return bloom. There was little effect on fruit drop attributable to PGR application, although ethephon and carbaryl treatments exhibited greater drop than NAA treatment on 'Ellis Bitter' in 2016. This is consistent with the use of NAA to prevent preharvest drop, however no PGR treatment was different from the control. There was concern that use of ethephon for return bloom promotion would enhance fruit maturity as measured by fruit firmness and starch index, but that does not appear to be the case in this study with no significant differences found among the treatments. Juice quality characteristics were not affected by any PGR treatment for any cultivar in either year of the trial (Table 3), and all juice quality values fell within normal ranges for the cultivars (Alexander, et al., 2016; Moulton, et al., 2010; Valois, et al., 2006).

That no effects were observed from PGR application on juice quality parameters essential for making high-quality cider is an important consideration in guiding future research and management of high-value cider orchards. This suggests that continued research on PGRs tailored to specific cider apple cultivars may be warranted without expectation for significant changes in juice quality. In this relatively short study, effect of PGRs on crop yield and biennial production were inconsistent. However, different and contradictory responses to PGRs used on 'Ellis Bitter' and 'Kingston Black' suggest that specific PGR programs may be suited to specific cultivars, as is the case with commonly grown dessert apple cultivars in the U.S. Continued study should be carried out separately on different cultivars and over a longer period to best evaluate long-term impact on biennialism.

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Table 2. Crop yield and fruit quality for two cider apple cultivars and six plant growth regulator treatments.

		Treatment[z]	No. fruit per tree	Kg fruit per tree	Fruit drop % (kg/kg)	Flesh firmness kg * cm^{-2}	Starch index[y]
2016	Kingston Black	NTC	84.2	9.7	48.2	8.92	4.72
		Carb	87.2	11.2	48.2	8.76	5.20
		NAA	164.	13.0	42.3	8.13	5.00
		Carb+NAA	76.8	10.6	46.2	8.48	5.75
		Eth	76.3	10.3	50.6	8.44	5.95
		Carb+Eth	86.8	11.7	57.1	7.23	5.50
		p-value[x]	0.1679	0.8042	0.5546	0.1153	0.168
2017	Kingston Black	NTC	1.2 ab[x]	0.06 ab	93.9	7.76	5.25
		Carb	0.3 b	0.03 ab	85.7	8.65	2.00
		NAA	0.8 ab	0.04 ab	66.8	9.93	5.42
		Carb+NAA	0.5 b	0.03 ab	72.6	7.95	7.00
		Eth	5.8 a	0.22 a	91.0	8.91	6.03
		Carb+Eth	0.0 b	0.00 b	-[w]	-	-
		p-value	0.0210	0.0423	0.7130	0.1238	0.357
2016	Ellis Bitter	NTC	187. ab	15.0	35.3 ab	7.81 a	7.45
		Carb	78.0 b	8.28	49.2 a	6.77 bc	7.24
		NAA	215. a	17.64	29.7 b	7.23 ab	7.30
		Carb+NAA	95.5 ab	11.13	34.7 ab	6.43 bc	7.23
		Eth	116. ab	10.96	46.8 a	6.55 bc	7.51
		Carb+Eth	102. ab	10.73	42.0 ab	6.17 c	7.55
		p-value	0.0138	0.0988	0.0087	< 0.0001	0.212
2017	Ellis Bitter	NTC	1.0	0.14	20.0	6.55	6.33
		Carb	24.5	2.22	27.0	5.90	6.79
		NAA	0.0	0.00	-	-	-
		Carb+NAA	12.0	1.87	17.0	5.92	7.37
		Eth	0.0	0.00	-	-	-
		Carb+Eth	1.8	0.18	29.2	5.30	7.25
		p-value	0.3889	0.2388	0.9137	0.4924	0.083

[z] From table 1.
[y] Relative starch index from Blanpied & Silsby,
[x] P-value for initial F-test at α=0.05. For p< 0.05, mean values for each treatment followed by the same letter do not differ using Tukey's adjustment for overall of multiple comparisons α=0.05.
[w] Missing data where harvest = 0.

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Table 3. Juice quality for two cider apple cultivars and six plant growth regulator treatments[z].

		Treatment[y]	Soluble solids (°brix)	pH	Titratable acidity (g malic * l^{-1})	Total polyphenols (mg * l^{-1})	Yeast assimilable nitrogen (mg * l^{-1})
2016	Kingston Black	NTC	13.6	3.28	5.44	1836	54.8
		Carb	13.8	3.29	6.00	1613	77.2
		NAA	13.5	3.33	5.25	1107	80.6
		Carb+NAA	13.5	3.33	5.54	1228	84.8
		Eth	14.0	3.35	4.83	1248	72.6
		Carb+Eth	13.6	3.34	5.10	955	82.5
		p-value	0.9851	0.7496	0.1246	0.2899	0.0881
2017	Kingston Black	NTC	14.3	3.49	3.87	1378	121.9
		Carb	13.1	3.46	5.86	1408	187.2
		NAA	15.3	3.38	5.97	2010	177.9
		Carb+NAA	12.1	3.68	3.59	1587	181.2
		Eth	13.4	3.44	4.10	2162	114.5
		Carb+Eth	*na*				
		p-value	0.8055	0.1936	0.4667	0.2827	0.0789
2016	Ellis Bitter	NTC	12.5	4.08	1.31	2753	83.7
		Carb	12.6	4.17	1.47	2523	82.1
		NAA	11.7	4.12	1.42	2363	111.2
		Carb+NAA	12.2	4.19	1.60	2255	124.2
		Eth	11.4	4.05	1.51	2207	100.3
		Carb+Eth	12.3	4.19	1.39	2398	80.2
		p-value	0.1141	0.0979	0.4574	0.2621	0.0790
2017	Ellis Bitter	NTC	12.5	4.33	1.27	2546	118.4
		Carb	12.4	4.28	1.15	2759	103.8
		NAA	*na*				
		Carb+NAA	12.6	4.36	1.49	2491	125.0
		Eth	*na*				
		Carb+Eth	12.9	4.43	1.31	3026	101.0
		p-value	0.9453	0.8671	0.2575	0.4937	0.8214

[z] Juice analysis methods Valois et.al., 2006.
[z] From table 1.
[x] P-value for initial F-test at α=0.05.
[w] Missing data where harvest = 0.

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