Effect of Summer Hedging on Return Bloom, Yield, Tree Growth, and Juice Quality of Apples Grown for Cider

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Abstract

As growers have started planting specifically for the production of fermented cider, new information is needed to understand how to maintain adequate annual crop yields and improve return bloom. Cider cultivars of European origin have been found to respond poorly to traditional crop load management methods using plant growth regulators and traditional return bloom sprays. In this study, tall spindle-trained cider apple cultivars 'Somerset Redstreak' and 'Harry Masters Jersey' and traditional dessert apple cultivars 'McIntosh' and 'Empire' were mechanically hedged in summer 2019 and 2020 to evaluate response on return bloom, yield, tree growth, and juice quality. Treatments consisted of 1) normal winter dormant pruning; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (pre-bloom) bud stage with hedger, and 4) mechanical pruning at 12-14 leaf stage, in mid-June. 'McIntosh', 'Empire', and 'Somerset Redstreak' each flowered and cropped in 2020, but 'Harry Master Jersey' had essentially no crop and was not affected by hedging. There was a noteworthy difference in canopy size for all cultivars the first season, with most hedging treatments being reduced nearly by half. Juice quality was unaffected by hedging treatment for soluble solid content, pH, titratable acidity, and total phenolics. Continued evaluation is needed to understand the long terms effects hedging has on return bloom.

Keywords: pruning, 'Harry Masters Jersey', 'Somerset Redstreak', 'McIntosh', 'Empire', biennial bearing

INTRODUCTION

Biennial or alternate bearing can be a serious problem for cider apple growers. Alternate bearing refers to a large crop of fruit in one year (the "on" year), followed by a small or no crop the following ("off") year (Moulton, 2010). In apples (*Malus × domestica*), the exact mechanism that leads to biennial bearing is not fully known, but it is linked to the flower development cycle. A complex of factors including hormones, nutrients, and carbohydrates contribute to the biennial cycle. Gibberellins are plant hormones produced by the seeds in developing fruit that have been shown to inhibit flower production (Chan, 1967). The critical mineral nutrients nitrogen, phosphorus, and boron are necessary for adequate flower induction (Grochowska, 1973; Neilsen et al., 1990; Wünsche and Ferguson, 2005). A heavy crop load in the on-year of biennial bearing apple trees depletes the tree's carbohydrate reserves, a lack of sufficient carbohydrates the following year leads to reduced flower formation in the off-year. (Grochowska, 1973). Competitive growth processes may also inhibit flower bud formation (Koutinas et al., 2010). Crop load management through flower and fruitlet thinning are common practices and have been found beneficial on flower bud formation and return bloom in 'Honey crisp' and 'York' trees (Robinson et al., 2010; Peck et al., 2016). Growers have relied primarily on chemical thinning to adjust crop load but certain cultivars, like European-origin cider apples, do not respond effectively to chemical thinning to manage biennial cropping habit (Merwin, 2008).

An alternative crop load management strategy is pruning. Pruning refers to the annual removal of old and/or damaged parts of trees, especially unproductive shoots and branches. Proper dormant and summer pruning can improve light penetration, airflow, and stimulate flower bud production (Lakso and Corelli Grappadelli, 1992). Hand pruning is a labor-intensive activity, and producers of cider fruit destined for processing are interested in

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reducing costs and labor with the use of mechanized pruning. Previous studies suggest that hedging may benefit 'McIntosh' and 'Empire' by increasing canopy volume and fruit color (Schupp, 1992; Ferree and Rhodus, 1993). Prior studies in Washington State (U.S.A.) recommend mechanical hedging during tree dormancy and the 12th leaf stage to initiate terminal bud set and expose fruit and potentially fruitful wood to sunlight (Lewis, 2018). Results varied across the five cultivars tested, but a decrease in return bloom was not recorded

Currently, little is published addressing how to manage cider apples or their potential for biennial bearing. Further cultivar-specific research is needed to understand the biennial tendencies of cultivars like "Somerset Redstreak" and "Harry Masters Jersey". This project aims to provide apple growers and cider producers with a better understanding of how different crop load and canopy management strategies influence the return bloom and juice quality at harvest of four apple cultivars.

MATERIALS AND METHODS

Field methods

Three mechanical hedging timings were compared for their effects on return bloom in cider and dessert cultivars trained to tall spindle. Treatments consisted of 1) normal winter dormant pruning with hand tools as a control; 2) mechanical winter dormant pruning with a hedger; 3) mechanical pruning at pink (pre-bloom) bud stage with hedger, and 4) mechanical pruning at 12-14 leaf stage, in mid-June (Lewis, 2018). Treatments were applied in a randomized complete block design, with six single-tree replications per treatment.

Replicated field trials were completed at two orchards in Chittenden and Addison County, Vermont. At the first site located in South Burlington, VT (SBVT) twenty-four 'Empire' and 'McIntosh' trees were selected for the trial. Established in 2011, trees were grafted onto 'Budagovsky 9' ('B.9') rootstock, spaced at 0.9m · 4.5m apart in Windsor Adams loamy sand soil with supplemental irrigation. The second location was a commercial orchard in Cornwall, VT (CWVT). Cider cultivars 'Somerset Redstreak' and 'Harry Masters Jersey' grafted on 'M.9 NIC29®' rootstock established in 2016 were planted at 0.9m · 4 m spacing in Nellis loam soil with supplemental irrigation. At both sites, orchard floor management consisted of mowing of the drive rows with a 1-m herbicide strip maintained under the canopies. Each planting followed standard commercial practices for irrigation, pest, and fertilization management.

Hedging was performed using a mechanical hedge trimmer (STIHL model KM 56 RC-E with HL-KM attachment, STIHL Inc. Virginia Beach, VA). Trees were trimmed to a fruiting wall measuring 0.3 m across the row using a measured guide attached to the trimmer, pruning all limbs to an equal length from the top to the bottom of each tree. Hedging performed during the growing season was completed when no rain was forecast for two days following the procedure to limit potential for fire blight infection.

'Somerset Redstreak' was recorded at full bloom on 21 May in 2019 and 2020 and 6 May in 2021. Fruit were harvested according to the grower's schedule on 16 Sept 2019 and 8 Sept 2020. 'Harry Masters Jersey' full bloom was recorded on 27 May 2019, 29 May 2020 and 7 May 2021. Fruit were harvested 30 Sept 2019, and 25 Sept 2020. 'McIntosh' came into full bloom 23 May 2019, 21 May 2020, and 6 May 2021 and were harvested on 19 Sept 2019, and 24 Sept 2020. 'Empire' full bloom was 24 May 2019, 21 May 2020 and 7 May 2021 and harvest was on 26 Sept 2019, and 28 Sept 2020.

Data collection

At full bloom, for each treatment-replicate, the total number of flower clusters on each tree was counted and recorded. Each fall, the vegetative growth parameters: tree height and spread (m), trunk circumference (cm), and the length of five terminal branches per tree were measured. At harvest, total crop yield (kg tree^{-1}) was measured and number of fruit per tree

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Table 1. Effects of three hedging times on bloom and crop yield of 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled from 2019 and 2020.

Cultivar/ Location Treatment [a]		No. of flower clusters per tree			Yield per tree (kg)		Yield efficiency (fruit/ TCSA kg cm^{-2})		Pre-harvest Drop (%)	
		2019	2020	2021	2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	288.8	238.2 A	217.2	13.99	18.58	0.99	1.25 a	2.6	4.1 ab
	D-HG	283.8	135.2 B	272.3	17.29	13.48	1.20	0.86 ab	1.5	8.9 a
	P-HG	262.2	132.7 B	280.5	12.45	12.53	0.84	0.86 ab	1.4	4.7 ab
	J-HG	338.5	183.2 AB	250.8	10.24	12.58	0.67	0.77 b	1.2	3.6 b
p-value[b]		0.219	0.003	0.5921	0.058	0.045	0.009	0.030	0.476	0.030
'Empire' SBVT	D-HP	159.8	131.3	211.2	8.09	6.51	0.74 a	0.53	0.6	4.1
	D-HG	158.7	121.7	217.3	6.57	6.11	0.56 ab	0.47	1.0	4.5
	P-HG	164.0	137.3	197.7	6.91	7.96	0.58 ab	0.60	1.3	1.4
	J-HG	140.5	97.5	178.8	5.74	6.01	0.53 b	0.51	0.4	2.3
p-value		0.770	0.238	0.6788	0.286	0.670	0.034	0.721	0.660	0.561
'Somerset Redstreak' CWVT	D-HP	111.8	33.2	194.8	4.72	2.75	0.43	0.23	37.8	24.4
	D-HG	75.3	70.3	116.2	3.94	4.38	0.34	0.39	24.0	9.4
	P-HG	49.8	27.5	214.2	3.12	3.97	0.28	0.32	23.5	12.7
	J-HG	59.2	55.3	158.5	2.74	3.09	0.24	0.28	36.2	14.1
p-value		0.534	0.670	0.7109	0.718	0.934	0.687	0.932	0.702	0.574
'Harry Masters Jersey' CWVT	D-HP	99.7	0.0	199.5	-	-	-	-	-	-
	D-HG	93.8	0.0	199.0	-	-	-	-	-	-
	P-HG	80.2	5.2	161.8	-	-	-	-	-	-
	J-HG	98.2	11.5	188.5	-	-	-	-	-	-
p-value		0.770	0.534	0.8096	-	-	-	-	-	-

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging
[b]P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

was recorded. Yield efficiency was calculated by dividing the total kg of fruit harvested by each tree's trunk cross sectional area (TCSA). The number of recently dropped fruits were recorded separately and assumed to be of average fruit weight as calculated from the other yield data. A randomly selected sample of five fruit per treatment-replicate (tree) was collected from harvested fruit and assessed for fruit weight (g), scored for red color, general defects, and USDA grade distribution (Bradshaw et al., 2018). After external evaluation, internal fruit qualities were assessed. Fruit firmness was measured using a 11-mm probe penetrometer (Wagner, Greenwich, CT), and ripeness assigned using the starch iodine index (Blanpied and Silsby, 1992). Using standard protocols, fruit samples were then analyzed for juice quality parameters, including pH, titratable acidity, total phenolics, and soluble solids (Bradshaw et al., 2018).

In 2019, due to a logistical error at the participating orchard, research fruit were collected by orchard picking crews, and harvest and juice data for 'Harry Masters Jersey' was unable to be collected. Titratable acidy and total phenolics were not collected for dessert cultivars 'McIntosh' and 'Empire'.

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Data analysis

Data were subject to analysis of variance (ANOVA) procedures by hedging treatment separately for each orchard location and year (JMP®, Version *15,* SAS Institute Inc., Cary, NC, 1989-2019). If overall variances were found at α=0.05, post-hoc multiple comparisons were made using Tukey's adjustment.

Table 2. Effects of three hedging timings on tree growth parameters of 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Autumn 2019 and 2020

Cultivar/ Location Treatment [a]		TCSA (cm^2)		Canopy area (m^2)		Terminal branch length (cm)	
		2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	15.8	17.7	9.1 AB	12.7	29.1	22.8 B
	D-HG	16.5	19.8	11.0 A	10.3	23.6	20.0 B
	P-HG	17.4	19.8	5.1 B	8.5	23.8	38.5 A
	J-HG	18.5	22.1	5.7 B	8.2	25.8	20.9 B
p-value		0.714	0.683	0.003	0.230	0.708	0.005
'Empire' SBVT	D-HP	9.4	11.7	4.2	4.9 a	15.8	16.8
	D-HG	10.5	13.2	4.2	3.6 ab	18.4	26.0
	P-HG	11.0	13.8	2.6	3.6 ab	18.1	22.5
	J-HG	9.0	11.1	1.8	2.7 b	20.2	24.4
p-value		0.627	0.520	0.031	0.038	0.797	0.212
'Somerset Redstreak' CWVT	D-HP	9.8	11.8	9.1	10.7	17.4 b	36.7
	D-HG	10.1	12.1	8.7	9.1	18.7 b	27.5
	P-HG	10.5	13.6	5.9	8.9	29.5 a	35.8
	J-HG	9.3	11.9	4.4	7.3	22.7 ab	32.5
p-value		0.772	0.613	0.038	0.393	0.016	0.848
'Harry Masters Jersey' CWVT	D-HP	12.8	16.5	6.2 a	7.7 A	15.5	27.5
	D-HG	13.3	17.5	4.6 ab	4.9 B	17.8	21.5
	P-HG	12.5	15.3	3.2 b	5.0 B	18.8	29.2
	J-HG	14.9	19.0	3.3 b	4.5 B	16.3	27.6
p-value		0.280	0.145	0.0007	0.001	0.282	0.177

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging

[b]P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

RESULTS AND DISCUSSION

Hedging treatments applied in 2019 were expected to affect the following season's flowering. In 2020, the dormant hand pruned treatment on 'McIntosh' had an average return bloom of 238 flower clusters per tree, 83% of the prior year's total. Hedging treatments on 'McIntosh' in 2019 had a 47-54% reduction in the number of returning flower clusters from the prior year (Table 1). This could be because there was less canopy volume and foliage to support flower development. There were no differences in bloom attributable to hedging treatment in 2021. In 2019 a trend toward reduced yield per tree and yield efficiency (yield per TCA) from hedging was observed for almost all cultivars, the exception being 'McIntosh'. Dormant hand pruned 'McIntosh' had an average 6 kg yield increase over any hedging treatment in 2020. 'Empire' hedged at pink bud stage had higher crop yield than dormant hand pruned trees in 2020. After the second year of hedging 'Somerset Redstreak' showed an increase in cumulative yield for all hedging times. The cropping of 'Somerset Redstreak' in

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2020 shows the potential for annual bearing tendencies for that cultivar. Previous studies on hedging 'Empire' suggests that hedging increases cumulative yield over a ten-year period (Ferree and Rhodus, 1993). Two years of data presented here are currently unable to fully support that statement, but hedging appears to be a promising management tool for both 'Empire' and 'Somerset Redstreak'. 'Harry Master Jersey' exhibited biennial tendencies, with very few trees flowering in 2020. This confirms the tendency for 'Harry Master Jersey' to be biennial and that following one-year of hedging, return bloom was not stimulated. More data are necessary to confirm this trend.

Hedging in 2019 narrowed the spread of the trees, reducing the canopy volume for each cultivar (Table 2). Hand-pruned trees were nearly twice the size of trees pruned mid-June. Hand pruned trees remained larger in 2020, but 'McIntosh' and 'Somerset Redstreak' did not show a difference among treatments. Summer hedging at pink stimulated shoot growth for 'Somerset Redstreak' and 'McIntosh' leading to a wider and denser canopy. No TCSA differences were observed in 2019 or in 2020 between trees hand pruned or hedged, across all four-cultivars surveyed.

Table 1: Juice quality at harvest for 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled autumn 2019 & 2020

Cultivar / Location Treatment [a]		SSC (°Brix)		pH		Titratable acidity (g malic L^{-1})		Total polyphenols (mg L^{-1})	
		2019	2020	2019	2020	2019	2020	2019	2020
	D-HP	11.7	11.0	3.27	3.11	-	8.85	-	-
'McIntosh'	D-HG	10.8	11.6	3.30	3.09	-	10.26	-	-
SBVT	P-HG	11.3	11.0	3.27	3.14	-	9.34	-	-
	J-HG	12.0	11.2	3.28	3.12	-	9.76	-	-
p-value [b]		0.420	0.164	0.784	0.608	-	0.171	-	-
	D-HP	12.3	12.6	3.35	3.22	-	8.88	-	-
'Empire'	D-HG	13.1	12.7	3.31	3.22	-	8.68	-	-
SBVT	P-HG	12.8	12.5	3.32	3.24	-	8.32	-	-
	J-HG	12.7	12.8	3.34	3.22	-	8.57	-	-
p-value		0.588	0.654	0.284	0.948	-	0.481	-	-
	D-HP	10.6	11.2	4.15	3.84	1.55	1.85	2719	2410
SSR	D-HG	12.2	11.6	4.15	3.94	2.10	2.01	3061	2305
CWVT	P-HG	11.3	12.1	4.06	4.05	1.68	2.59	2205	3135
	J-HG	11.2	12.2	4.14	3.99	1.70	2.10	2556	3169
p-value		0.462	0.834	0.802	0.517	0.395	0.531	0.440	0.370

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging

[b] P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

Juice chemistry (Table 3) was within a normal range for all cultivars and there were no differences in juice quality for soluble solids, pH, titratable acidity, or total phenolic among treatments (Alexander et al., 2016; Bradshaw et al., 2018). This shows that canopy management done throughout the year and altering tree structure via hedging does not negatively affect juice quality. These results provide apple growers and hard cider producers with a better understanding of how different crop load and canopy management strategies influence juice quality at harvest. Fruit quality parameters (Table 4) for red color, firmness, and starch index rating remained unaffected by treatment. Although summer hedging opened up the canopy to allow potentially more light penetration into the tree, there were no increases in fruit color observed on hedged trees. There were no differences in fruit firmness and starch indexes at α error of 0.05. This did not agree with previous work which showed increases in fruit color, softer fruit, and higher starch indices on summer pruned 'McIntosh' trees (Schupp, 1992).

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Table 4. Fruit quality at harvest for 'McIntosh', 'Empire', 'Somerset Redstreak' and 'Harry Masters Jersey' in Vermont. Sampled autumn 2019 and 2020

Cultivar /Location Treatment[a]		Red Color (%)		Flesh firmness (kg cm^{-2})		Starch pattern index	
		2019	2020	2019	2020	2019	2020
'McIntosh' SBVT	D-HP	85	82	7.9	7.5	5.4	5.5
	D-HG	85	78	7.7	7.3	6.0	4.8
	P-HG	92	70	7.8	7.3	5.7	5.2
	J-HG	95	80	8.0	7.2	5.1	5.2
p-value		0.1660	0.1014	0.7565	0.6717	0.0965	0.2624
'Empire' SBVT	D-HP	92	93	9.0	8.6	3.4	4.2
	D-HG	96	93	9.2	8.4	2.9	4.6
	P-HG	94	91	9.1	8.3	3.3	4.8
	J-HG	91	89	9.2	8.4	2.9	4.9
p-value		0.0921	0.2744	0.9515	0.7204	0.3115	0.0661
'Somerset Redstreak' CWVT	D-HP	73	58	7.6	8.8	4.1	3.7
	D-HG	64	57	7.8	8.2	4.2	4.4
	P-HG	75	50	7.7	8.7	3.5	5.1
	J-HG	75	58	7.5	8.5	4.3	5.1
p-value		0.6401	0.9427	0.5281	0.9714	0.7357	0.6351

[a] D-HP =dormant hand pruning, D-HG = dormant hedging, P-HG= pink hedging, J-HG= June hedging
[b]P-value for overall ANOVA for treatment effects within each orchard/year. Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment.

Hedging during the summer caused tissue damage to tree limbs and shoots, leaving a splintered 'broomstick' effect on the end of trimmed branches. Pruning trees mid-season can carry an increased risk of fire blight infection. Fire blight caused by the bacterium *Erwinia amylovora* is a destructive disease that causes dieback of blossoms, shoots, limbs and under ideal conditions can kill the tree. Hedging at pink and mid-June causes wounds that fire blight bacterium can enter. Infected trees can develop lesions that ooze orange bacterium filled liquid that is easily spread in moist, warm weather, by splashing rain, dew, wind and insects. The use of hedging equipment can also spread disease if not properly sanitized. Damaged branches that have dead tissue also have the potential to host a range of fungal diseases, such as black rot (*Botryosphaeria obtusa*) that can infect fruit and form cankers. Disease management for 'McIntosh' and 'Empire' is well understood, but the fire blight and disease susceptibility of 'Harry Master Jersey' and "Somerset Redstreak' grown in the northeastern U.S.A. is less well-established. No fire blight damage was seen in this study, likely in part due to proper sanitation and timing hedging treatments around weather conditions. Growers would benefit from a robust disease assessment on damage caused by hedging and the incidence of disease.

CONCLUSIONS

Although conducted over a relatively limited in time, results of this study suggest that summer canopy management may not alter apple juice quality for cider making. 'Harry Masters Jersey' showed a tendency for biennial bearing, and summer hedging was unable to stimulate return bloom. 'Empire' and 'Somerset Redstreak' may both benefit from hedging, with those cultivars showing signs of increased yields and annual bearing. Future studies should continue to record flowering and yield of 'Somerset Redstreak' and 'Harry Masters Jersey' to establish a biennial bearing index. Based on the two years of data presented, 'McIntosh' trained to tall spindle may not be suitable for hedging due to decreased yields and return bloom in hedged trees. Both cider cultivars would benefit from study of specific crop load management in which trees are hand-thinned to specific fruiting densities based on TCSA

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in order to determine optimal crop load for those cultivars. More research-based information is needed to understand the flowering and cropping of specialty cultivars to inform growers on how to maintain consistent annual production on those, like 'Harry Master's Jersey', that have pronounced biennial tendencies.

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