Modified pruning intensity may reduce labor costs and improve profitability of growing dessert apple cultivars for cider production.

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ABSTRACT

Annual pruning of apple tree canopies is a common and recommended practice in commercial orchards. Pruning is performed to renew vegetative and reproductive wood, to improve sunlight and air penetration into the tree canopy, and to develop and maintain tree structure. However, annual pruning, particularly of relatively large, mature trees, is among the highest labor expenses in orchards. In recent years, substantial growth in the production and sales of fermented cider has led to increased demand for fruit from cideries. While prices for traditional dessert cultivar fruit from cideries have increased, they remain uncompetitive with prices from the fresh fruit market for those same cultivars. In order to meet price points for cider apples, cost reductions are sought through reduced pruning intensity which may improve profitability, but may come at the sake of fruit quality or long-term crop yield. In this experiment, mature, freestanding 'McIntosh' and 'Empire' trees on semidwarf rootstock on two farms in Vermont received different pruning intensity and were evaluated for crop yield, fruit quality, net income, and juice characteristics important to cidermaking. There were few differences attributable to pruning treatment for most assessed parameters. Non-pruned trees had improved net income over pruned trees in both orchards, but all treatments showed negative profitability under a model where fruit were sold solely to cideries instead of to higher-valued fresh markets.

Keywords: *Malus x domestica, juice quality, light interception, semidwarf orchards, market comparison*

INTRODUCTION

Apple production in Vermont has been relatively stable at approximately 800,000 bushels and $11 million annual revenue since the late 1990s (NASS, 2016). Fermented cider (hereafter referred to as 'cider') production has increased dramatically in the U.S. in recent years with average annual growth exceeding 50% between 2009 and 2014 and revenues totaling $292.5 million (Petrillo, 2014). Sixteen Vermont hard cider producers (hereafter referred to as 'cideries') purchased over 200,000 bushels of local fruit primarily of traditional dessert cultivars (e.g. 'McIntosh', 'Cortland') in 2014 at an average price of $5.75 per bushel, which is only 30% of the price received for fresh market apples (Becot et al., 2016). In Vermont, orchards of traditional dessert cultivars are being managed specifically to provide fruit to this expanding market, but prices paid for processing fruit remain below those for fresh market apples. In order to meet demands for fruit supply at lower price points, growers must adapt management to reduce inputs and labor without compromising crop yield or quality. Expansion of the cider industry represents a potential opportunity for Vermont apple growers, but production methods which reduce costs to meet lower price points paid for cider fruit compared to the fresh dessert fruit market must be adopted to ensure profitability. Because cideries have greater tolerance for small, blemished, or poorly-colored fruit, reduced-intensity management practices may produce acceptable quantities of fruit with desired quality to be profitable for the grower.

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Pruning and tree training are annual tasks performed in orchards to manage tree form, improve pest management, increase fruit size, and enhance red color (Ferree and Schupp, 2003). Some prior research estimates that pruning accounts for approximately 25% of labor costs in moderate- to high-density production systems in which trees are intensively pruned every year to optimize fruit quality (Quamme et al., 1996). Reduced pruning intensity in orchards managed for cider apple production may improve overall orchard profitability, but reduced crop production or quality below standards required by cideries as a result of changes in pruning practices could make cider apple production unprofitable for growers who typically sell apples to the fresh market. In this study we explored effects of modified pruning schedules on crop yield, fruit grade, and juice quality.

MATERIALS AND METHODS

Research was conducted in two orchards in the Champlain Valley of Vermont (Köppen-Geiger classification Dfb, USDA cold hardiness zone 4b) in 2016 and 2017. The first site was located at the UVM Horticulture Research and Education Center in South Burlington, VT. Trees were 'Empire' trees on M. 7 rootstock planted in 1992 at 521 trees * ha^{-1}; soil is a Windsor-Adams loamy sand with supplemental irrigation. Site two was located at a commercial orchard in New Haven, VT with 'McIntosh' trees on M.26 rootstock planted in the 1980s at 402 trees * ha^{-1} on Vergennes clay soil without irrigation. In each orchard, standard commercial practices for pest management, fertilization, and groundcover management were applied to the entire planting. One key difference between the sites was that the South Burlington orchard was and has long been managed for dessert apple production with regular and intensive pruning and a thorough pest management program. In the New Haven orchard, apples were grown primarily for cider production and the orchard was managed for the previous two seasons with relatively light pruning and a minimal pest management program.

Because the original planting design of the South Burlington orchard included four cultivars in a completely randomized design (CRD), the four pruning treatments were applied in a CRD to 'Empire' cultivar only with six single-tree replications per treatment. Treatments in the New Haven orchard were applied in a randomized complete block design, with six single-tree replications per treatment. Treatments included: (1) no dormant or summer pruning; (2) no dormant pruning followed by summer pruning; (3) standard 'commercial' dormant pruning with no summer pruning; and (4) commercial pruning followed by summer pruning. The 'no pruning' treatments included minimal cuts to remove broken branches or branches that interfered with overall tree structure. Summer pruning treatments were limited to removal of current season's vertical vegetative shoots in the canopy to improve light penetration. Standard dormant pruning followed standard procedures for maintaining freestanding central leader trees (Bound and Summers, 2001; Ferree and Schupp, 2003). Dormant pruning was performed in February or March, and summer pruning in mid-August prior to harvest.

Data Collection

For each treatment-replicate, data was collected at harvest for total crop yield (kg/tree) A randomly selected sample of 25 fruit per treatment-replicate (tree) was collected from harvested fruit and assessed for fruit size, color, general defects, and USDA grade distribution (Bradshaw et al., 2015). Fruit were categorized into 3 grades: 'US#1' (which included 'US#1','Fancy', and 'Extra Fancy'); 'Utility', (which included all fruit below 'US#1' grade, all small fruit between 139 and 100 grams weight, and free from punctures that would prevent sales to processors); and 'Cull', (which included all fruit below 100 grams, with flesh punctures, and with rots that would prevent from using in processed products.). A sub-sample of ten fruit collected from the grading sample was analyzed for juice quality parameters including pH, titratable acidity, total phenolics, and soluble solids using standard protocols (Miles and King, 2014).

Time to complete each pruning treatment was recorded each season. However, data from the New Haven site was incomplete. Because trees were similar in size and pruning time similar between the orchards, data were used from the South Burlington for both orchards. Net income per hectare was calculated using the formula:

kg yield * (n trees*ha^{-1}) * % 'US#1' grade * $1.32 $us*kg-1 +
kg yield * (n trees*ha^{-1}) * % 'Utility' grade * $0.33 $US*kg^{-1} –
mean expenses per ha – mean pruning cost per ha

Management costs were collected from a recent survey of cider apple growers in Vermont (Becot et al., 2018), and prices paid for fruit from a separate survey of the same population of growers (Becot et al., 2016). Cumulative net income was summed over the two study years. Because numerous assumptions and calculations were made in determining net income, these data are presented as descriptive only without ANOVA analysis.

Data analysis

Data were subject to analysis of variance (ANOVA) procedures by pruning treatment separately for each orchard site and year (SAS Institute Inc., 2002-2010). If overall differences were found at α=0.05, post-hoc multiple comparisons were made using Tukey's adjustment. Net revenue data were tabulated in Excel as descriptive only, and not subjected to ANOVA due to low statistical power resulting from multiple assumptions and calculations used.

RESULTS AND DISCUSSION

Crop yield was generally consistent across treatments in each orchard (Table 1). Only in South Burlington in 2017 were there differences among treatments, where the non-pruned trees had greater yield than the summer pruned trees. Non-pruned trees also had the highest ranked crop yield in 2016, although the difference was not significant at p=0.05. We attribute this to the increase in tree canopy that the non-pruned trees had attained after two years without pruning. That orchard was pruned by default to produce fresh market fruit with annual, relatively heavy pruning. Thus, cessation of pruning allowed for substantial expansion of the tree canopy. It would be expected that over the long-term this would lead to a dense canopy and reduced fruit bud development in the lower canopy but after only two years of reduced pruning, this had not likely occurred. That there was little difference in within canopy light levels at mid-day among treatments supports this hypothesis. In New Haven, there were no differences in yield among pruning treatments. This orchard had been managed for several years solely for production of cider apples, and in order to reduce costs, the trees had been minimally pruned (and sprayed) for several years before this study. Thus, the growth habit was bushier and canopies were more dense than the trees in South Burlington, and even when relatively heavy pruning was performed, the vigorous trees tended to respond by producing a flush of vegetative growth. Therefore the overall change in canopy size and density was more minimal in this orchard than in the more intensively-managed South Burlington orchard, which likely affected yield less among pruning treatments.

Table 1: Crop yield, mean individual fruit weight, and percent red color at harvest for four pruning treatments in two orchards.

Orchard	Year	Treatment[z]	Kg fruit/tree		Fruit weight (g)		Red color (%)
South Burlington	2016	WP	40.6		161.3		83.9
		WPSP	68.7		151.6		85.9
		NP	73.9		158.0		81.2
		SP	30.7		152.0		80.8
		p-value[y]	0.0757		0.6632		0.7562
	2017	WP	96.7	ab[x]	166.7		84.3
		WPSP	88.4	ab	167.7		89.4
		NP	123.2	a	163.1		84.8
		SP	74.2	b	169.6		85.4
		p-value	0.0183		0.8914		0.7475
New Haven	2016	WP	39.6		114.0		41.3
		WPSP	56.1		123.5		47.6
		NP	61.1		109.6		46.2
		SP	62.3		115.9		39.9
		p-value	0.4298		0.3478		0.6492
	2017	WP	56.4		148.3	a	79.3
		WPSP	54.6		146.5	ab	90.8
		NP	53.3		125.0	b	84.5
		SP	48.0		130.3	ab	91.9
		p-value	0.8409		0.0194		0.0742

[z]WP = winter pruned, WPSP = winter and summer pruned, NP = not pruned, SP = summer pruned
[y]P-value for overall ANOVA for treatment effects within each orchard/year
[x]Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment

Only in 2017 in the New Haven orchard were there differences in fruit size among pruning treatments, with larger fruits from winter pruned trees than non-pruned trees. The experimental design did not allow for direct comparison between orchards, but in all cases the treatment mean for fruit weight was lower for New Haven trees than for South Burlington trees. Some of this could be assumed to be cultivar related, although neither 'McIntosh' nor 'Empire' is known among growers to produce particularly large or small fruit. In fact, recommendations for the New England region recommend more aggressive thinning for 'Empire' partially in order to improve fruit size (Clements et al., 2015). It is more likely that the low-input management system used in the New Haven orchard has led to generally greater fruit shading and lower fruit size overall tan in the South Burlington orchard. That hypothesis is supported by similar pattern for red color development between the two orchards, where the South Burlington orchard produced redder fruit than the New Haven orchard in 2016 and to a lesser degree in 2017. Red fruit color development is strongly correlated with two factors with 'McIntosh' and 'Empire', direct sun exposure to the fruit and cool temperatures during ripening. One reason for the increased interest in high density apple training systems in recent years is the improved sunlight interception which improve fruit size and color compared to lower-density systems (Robinson, 2006; Robinson et al., 1991). In 2016, night temperatures during ripening were unusually warm, so red color development was not promoted and fruit required direct sunlight exposure to develop acceptable color. In 2017, more typical cool night temperatures were experienced and fruit from both orchards had more similar color.

Fruit weight and red color are two important components in conjunction with absence of pest damage, disease symptoms, and abiotic defects of USDA fruit grade determination (USDA, 2002). There was no difference among treatments within either orchard or year for distribution of fruit into grades in this experiment (Figure 1). However, between the two orchards, there were apparent but not statistically analyzable differences in fruit grade distribution, with the New Haven fruit, again,

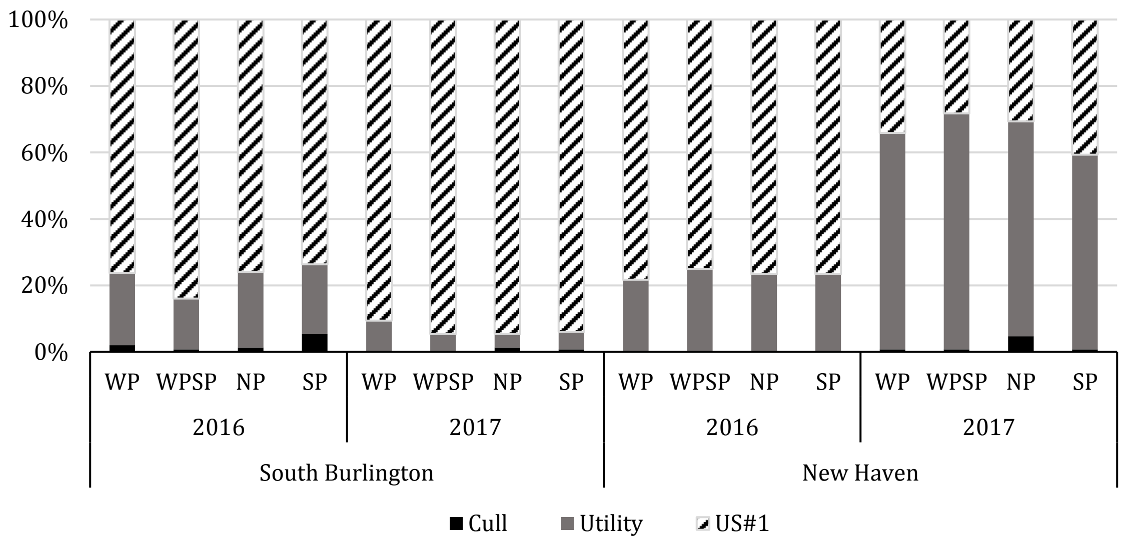

Figure 1. USDA grade distribution for harvested fruit from two orchards in 2016 & 2017 which received winter pruning (WP), summer pruning (SP), both pruning (WPSP) or no pruning (NP) treatments

managed for cider apples with less overall pruning, pest management, and groundcover management, having greater incidence of 'Utility' grade fruit, particularly in 2017. In both orchards and both years, the incidence of culled fruit was relatively low.

Net income was higher when the 'US#1' fruit were sold to fresh market and only 'Utility' fruit sold to the lower-valued cider market (Table 2). In all cases, selling the fruit entirely to cideries resulted in a net loss of income. However, storage and sorting costs are not included in this assessment, so profitability of the split-market model would be lower than presented, In addition,

Table 2: Net income ($US *ha^{-1}) over two seasons and sold to fresh apple ('US#1' grade)' + cider ('Utility' grade) or cider-only markets.

	Fresh + cider	Cider
South Burlington		
Winter	$ 21,490	$ (5,298)
Winter & Summer	$ 28,849	$ (4,014)
No Pruning	$ 39,068	$ (351)
Summer	$ 12,569	$ (7,834)
New Haven		
Winter	$ (2,098)	$ (10,248)
Winter & Summer	$ (1,328)	$ (9,632)
No Pruning	$ (44)	$ (8,873)
Summer	$ 740	$ (9,389)

management costs per acre used in both scenarios are based on actual data collected from Vermont farms, but those orchards were managed for fresh fruit and thus may have had higher input and labor costs than an orchard managed for cider apples where fruit size and freedom from defects is less of a concern. In both orchards and both sales scenarios, the no pruning treatment had the greatest (or least negative) net income.

Table 3: Juice quality at harvest for four pruning treatments in two orchards.

Orchard	Year	Treatment[z]	SSC (°brix)	pH	Titratable acidity (g malic * L-1)	Total polyphenols (mg * L-1)	Yeast assimilable nitrogen (mg * L-1)
South Burlington	2016	WP	11.8	3.40	5.98	213.9	36.5
		WPSP	11.5	3.38	5.52	210.1	33.7
		NP	11.4	3.37	5.70	210.1	28.3
		SP	11.3	3.39	6.10	210.6	32.5
		p-value[y]	0.8066	0.7630	0.3575	0.9959	0.6372
	2017	WP	11.8 ab[x]	3.26	5.83	196.4	25.0
		WPSP	12.3 a	3.23	6.19	216.4	25.3
		NP	11.6 ab	3.28	5.65	185.4	29.9
		SP	11.5 a	3.26	5.73	190.7	29.1
		p-value	0.0452	0.5224	0.2269	0.3793	0.7921
New Haven	2016	WP	10.5	3.13	8.30 a	1090.4	23.2
		WPSP	10.3	3.17	7.53 ab	952.0	22.4
		NP	10.8	3.13	7.71 ab	936.5	21.0
		SP	10.0	3.15	7.18 b	834.3	26.2
		p-value	0.3448	0.4024	0.0141	0.4846	0.6278
	2017	WP	11.6	3.13	9.66	798.8	24.0
		WPSP	12.1	3.15	9.58	861.4	30.8
		NP	12.4	3.12	10.37	1107.3	24.9
		SP	11.9	3.13	9.54	1104.1	24.6
		p-value	0.3179	0.6334	0.3078	0.1222	0.5848

[z]WP = winter pruned, WPSP = winter and summer pruned, NP = not pruned, SP = summer pruned
[y]P-value for overall ANOVA for treatment effects within each orchard/year
[x]Mean values followed by the same letter are not different at α=0.05 using Tukey's adjustment

Juice quality, presented in Table 3, was not different among all treatments and years and within each orchard and cultivar, and all values were consistent with the normal range for the cultivars (Bradshaw et al., 2018). This indicates that canopy management including altered pruning practices does not affect juice quality.

CONCLUSIONS

A shift in orchard management to produce lower-value fruit for cideries must be accompanied by lower fixed and variable costs. However, reduction of labor and material inputs into Northeastern U.S. apple orchards in order to meet lower price points paid for cider apples entails substantial risk. Unlike regions where relatively lower land prices, higher average yield, and a robust processing industries support apple production specifically for processing markets, New England apple growers typically produce for high-value fresh market sales outlets (Bradshaw, 2013; VTFGA, 2011). This study considered potential impacts on reduced pruning practices on crop yield, fruit and juice quality, and economic returns to growers. Overall, reduced pruning practices may improve modeled net income in the two orchards where this experiment was conducted, but in all cases the production of dessert cultivar fruit for a low-price cider market resulted in negative profitability. Fruit grown specifically for cideries must therefore be inherently higher valued, e.g., specialty cider cultivars, or labor and other input costs reduced more substantially than with modified pruning practices.

A substantial shortcoming of this experiment was the mismatch between the two orchards. The South Burlington orchard has been managed, despite being located on a research facility, as a fresh market orchard, with a complete complement of management practices including aggressive annual pruning, regular cropload management through chemical thinning, regular groundcover management, irrigation, and a comprehensive Integrated Pest Management (IPM) program. In contrast, the New Haven orchard was managed with a low-input strategy. Future work may consider higher-level analysis of orchard systems including historic management and more detailed economic parameters that differ between the systems. In the meantime, it is likely that the U.S. dessert cultivar cider apple industry will continue to operate secondary to higher-value fresh fruit markets.

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