Fruit mass, colour and yield of ‘Honeycrisp’™ apples are influenced by manually-adjusted fruit population and tree form

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SUMMARY
The influence of three manually-adjusted crop loads [3, 6 and 9 fruit cm–2 trunk cross-sectional area (TCSA)] on ‘Honeycrisp’™ apple (Malus domestica Borkh) quality and canopy volume were compared with unadjusted control trees. The crop-load treatments were applied at three sites over two consecutive seasons at 50 days after full bloom (DAFB). Sixteen trees at each site were selected annually, with the treatments being applied in a randomised-complete-block design. Fruit mass and fruit colour (%) were used to assess quality at harvest, while yield was determined by the mass (kg) of fruit cm–2 TCSA. The canopy volume (CV) for each tree was calculated following harvest and used as a covariate in determining its influence on fruit size and colour. As crop load decreased, harvested fruit mass and % red colour increased. For similar crop-load adjustments, larger tree CVs (in m3) resulted in greater fruit mass. Crop load and fruit-canopy density (fruit m–3 CV) were more highly correlated with fruit mass than with % fruit colour. The highest fruit quality occurred at the three and six fruit cm–2 TCSA. In addition, manually adjusting the crop-load at 50 DAFB did not eliminate the disposition of ‘Honeycrisp’™ towards biennial bearing in Nova Scotia’s climate.

The apple cultivar ‘Honeycrisp’™ has attracted the attention of North American apple producers, marketers and consumers (Rosenberger et al., 2004). The cultivar is hardy, not prone to Winter injury, and has an exceptionally crisp and juicy texture with a distinctive mottled red colouration over a yellow background (Luby and Bedford, 1988). The northerly, but moderate, maritime climate in Nova Scotia proved ideal for growing premium-coloured ‘Honeycrisp’™ fruit which resulted in a valuable export market with the potential to markedly rejuvenate the Nova Scotia apple industry.

Growing this unique cultivar, however, presents several challenges. Contrary to the initial characterisation of ‘Honeycrisp’™ reported in the U.S. Patent Office by Luby and Bedford (1988), this cultivar has produced extraordinarily heavy crop loads with a strong tendency towards biennial bearing in Nova Scotia and the northeastern states (Crassweller et al., 2005; Robinson and Watkins, 2003; Embree and Nichols, 2005). Excessive cropping contributes to a cycle of alternate season bearing (Robinson and Watkins, 2003; Crassweller et al., 2005), which results in a large number of small, poor quality apples on a tree in heavy bloom years (Forshey, 1986). Thus, proper management of crop-load in ‘Honeycrisp’™ becomes critically important for consistent production of marketable fruit.

Diverse orchard management practices and orchard designs among producers are common. Westwood and Roberts (1970) reported that the correlation between trunk cross-sectional area (TCSA) and the production potential of a tree is affected by different tree management and pruning regimes. Fruit thinning improves the leaf:fruit ratio by increasing the leaf area available to each of the remaining fruit (Forshey, 1986; Koike et al., 2003). The relationship between trunk size and tree canopy appears to diminish as the age of the planting system increases (Strong and Azarenko, 2000; Mielke and Smith, 2003). Wright et al. (2005) reported that the contour method of measurement for apple tree canopy volumes (CV) accounted for greater variation in fruit sizes compared to TCSA measurements.

Therefore, the objective of this work was to determine the influence of adjusting ‘Honeycrisp’™ trees to 3, 6 or 9 fruit cm–2 TCSA, at 50 DAFB, on fruit mass, colour, yield and biennial bearing, and to gauge the consistency of the response across three sites.

MATERIALS AND METHODS
Establishment of sites and blossom cluster density
Three separate grower sites with 7 year-old ‘Honeycrisp’™ trees on M.26 rootstocks were selected in the Annapolis Valley, Nova Scotia, Canada (45°03′00″N, 64°36′00″W). At the time of orchard establishment, all trees were 1 year-old and were feathered with a minimum trunk diameter of 1.6 cm. Planting densities...
and tree form varied between sites (Table I); however, TCSA values were similar, as shown in Table II. The TCSA of each tree was derived from a circumference measurement 30 cm above the graft union. In May 2003, 16 trees per site were selected and assigned to one of four blocks on the basis of similar numbers of blossom clusters cm\(^{-2}\) TCSA. Each of the four crop-load treatments (untreated control, 3, 6 or 9 fruit cm\(^{-2}\) TCSA) were then assigned at random to one tree in each block. New trees were selected in 2004 to avoid residual effects from the 2003 crop-load adjustment treatments. Blocking and treatment assignments in 2004 were similar to those in 2003.

**Measurements during the growing season**

Average blossom cluster and fruit number data were recorded following two full tree counts, which differed by less than 10% and were performed by two independent counters. Each experimental tree was evaluated at least twice per developmental stage. When necessary, successive counts were performed until these criteria were satisfied.

Fruit-number counts were completed on all trees across all sites at three different stages during fruit development in 2003, and in 2004. First stage counts were in the week prior to full bloom (FB) in late May, to assess blossom cluster density. Second stage counts occurred 20–25 days after full bloom (DAFB), after unfertilised fruit had been aborted, to determine the percentage fruit set. The last stage of counts occurred 50 DAFB, following the late natural drop in July, and was associated with the crop-load adjustment. Two full tree fruit-number assessments were required for this last stage (minimum of four counts) as fruits were manually removed in steps.

**Harvest and grading**

The green-to-yellow change in background skin colour was used as an indicator of maturity and optimum harvest date. Consequently, all treatments were harvested approx. 125 DAFB, which occurred during the first full week of October. Immediately after harvest, the mass and colour of every apple from each treatment tree were recorded. The colour rating was evaluated visually as the percentage of the epidermal surface area having a red-orange blush.

**Canopy volume (CV)**

CV was estimated for each individual tree using a geometrical model referred to as the “contour method” ([CV = (\(\pi \times a \times b \times h\)) / (m(x) + m(y) + 1]). The dimensions \(a\) and \(b\) are measurements of the width of the tree at the base of the canopy, perpendicular and parallel to the tree row orientation, respectively. The height of the canopy \(h\) is measured from the lowest branch to the apex. The functions \(m(x)\) and \(m(y)\) were derived to accommodate the contour of the tree (Wright et al., 2005). CV measurements were made after harvest in October 2003 and 2004. To exclude any inherent treatment effects, the Autumn measurements did not include seasonal growth.

**Subsequent-year bloom**

The return bloom (RB) was recorded on each experimental tree in both years at full bloom (FB), in May, using full-tree blossom cluster counts.

**Statistical analysis**

The treatments (untreated control and 3, 6 or 9 fruit cm\(^{-2}\) TCSA) were arranged as a randomised-complete-block design, which was replicated over two seasons. Blocks were based on similar blossom cluster density (blossoms cm\(^{-2}\) TCSA), with four blocks of four trees each at each of the three sites selected each year. The four crop-load adjustment treatments were assigned at random to trees within each block (see Establishment of sites and blossom cluster density above). The experimental design used 96 trees year\(^{-1}\), with each tree being considered an experimental unit. The data were analysed using the ANOVA procedure (Genstat Release 7.1). CV was used as a covariate to normalise the fruit-canopy density calculations. Unless noted otherwise, only results significant at \(P \leq 0.05\) are discussed.

### RESULTS AND DISCUSSION

#### Site and tree-size analysis

Covariance analysis indicated a highly positive

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**Table I**

<table>
<thead>
<tr>
<th>Site</th>
<th>Spacing (m × m)</th>
<th>Hectare(^{2})</th>
<th>Tree Form</th>
<th>TCSA (cm(^2))</th>
<th>Canopy volume (m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2003</td>
<td>2004</td>
</tr>
<tr>
<td>1</td>
<td>1.5 × 4.5</td>
<td>1.481</td>
<td>‘Slender spindle’ (3 wire)</td>
<td>22.4</td>
<td>24.0</td>
</tr>
<tr>
<td>2</td>
<td>2.0 × 5.5</td>
<td>0.885</td>
<td>‘Palmette’ (5 wire trained)</td>
<td>26.6</td>
<td>24.8</td>
</tr>
<tr>
<td>3</td>
<td>1.8 × 5.0</td>
<td>1.111</td>
<td>‘Staked spindle bush’</td>
<td>24.2</td>
<td>26.6</td>
</tr>
</tbody>
</table>

\(^{2}\)2003 and 2004 harvest data combined.

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**Table II**

<table>
<thead>
<tr>
<th>Crop load adjustment treatment</th>
<th>TCSA (cm(^2))</th>
<th>Crop load (fruit cm(^{-2}) TCSA)</th>
<th>Fruit mass (g)</th>
<th>Yield (kg cm(^{-2}) TCSA)</th>
<th>Colour (% red)</th>
<th>Canopy volume (m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (untreated)</td>
<td>25.6</td>
<td>17.1</td>
<td>113</td>
<td>1.62</td>
<td>46.1</td>
<td>2.95</td>
</tr>
<tr>
<td>3 fruit cm(^{-2}) TCSA</td>
<td>24.3</td>
<td>3.3</td>
<td>217</td>
<td>0.74</td>
<td>60.7</td>
<td>2.95</td>
</tr>
<tr>
<td>6 fruit cm(^{-2}) TCSA</td>
<td>25.5</td>
<td>6.4</td>
<td>171</td>
<td>1.11</td>
<td>55.3</td>
<td>3.07</td>
</tr>
<tr>
<td>9 fruit cm(^{-2}) TCSA</td>
<td>24.2</td>
<td>9.5</td>
<td>140</td>
<td>1.32</td>
<td>52.1</td>
<td>2.91</td>
</tr>
<tr>
<td>LSD(_{0.05})</td>
<td>2.17</td>
<td>0.53</td>
<td>10.9</td>
<td>0.12</td>
<td>2.86</td>
<td>0.46</td>
</tr>
<tr>
<td>Site (F prob.)</td>
<td>0.33</td>
<td>0.005</td>
<td>0.03</td>
<td>0.02</td>
<td>0.32</td>
<td>0.002</td>
</tr>
<tr>
<td>Linear crop-load (F prob.)</td>
<td>0.96</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>0.88</td>
</tr>
<tr>
<td>Site × Linear crop-load (F prob.)</td>
<td>0.84</td>
<td>0.76</td>
<td>0.003</td>
<td>0.34</td>
<td>&lt; 0.001</td>
<td>0.30</td>
</tr>
</tbody>
</table>
correlation ($P < 0.001$) between TCSA and CV (data not shown). Unlike TCSA, there were differences in CV between sites and years (Table I; Table II). The high positive correlation between TCSA and CV was unique for individual sites (Table I).

**Crop-load**

Crop-load showed differences between the 3, 6 or 9 fruit cm$^{-2}$ TCSA treatment adjustments (Table II). Also, untreated (control) trees had different crop loads between sites (Table II). Inter-site differences for the untreated controls may have resulted from the individual tree forms, planting densities and CVs, which varied between sites (Table I). The spur density within the tree canopy may also have been a factor that affected fruit populations in the untreated controls and crop-loads prior to fruit adjustment. This variable was not accounted-for in this experiment, but may warrant further study.

Weather data for the region indicated that during the 2003 blossom period (24 May to 1 June), 107 Crop Heat Units (CHU) and 19.7 sun hours (sh) occurred, whereas the 2004 season had 41 CHU and 10.3 sh (Environment Canada, 2005). In 2003, the three sites averaged 19.9 fruit cm$^{-2}$ TCSA prior to fruit adjustment 50 DAFB. In 2004, the three sites averaged 13.3 fruit cm$^{-2}$ TCSA. The poor pollination conditions in 2004 also reduced the amount of fruit removal required at 50 DAFB for all three crop-load adjusted treatments. Consequently, a greater number of lateral fruit and multiple fruit clusters, which would result in smaller sized fruit (Denne, 1963), were retained after crop-load adjustment in 2004. Many of these lateral fruit and multiple fruit clusters would have been removed during the manual fruit adjustment stage in 2003.

**Fruit mass**

The mean fruit mass differed between treatments, with increased mean fruit mass occurring at the lower crop loads (Table II). The correlation between crop-load [(fruit cm$^{-2}$ TCSA), (x)] and mean fruit mass (y) varied between sites (Figure 1; Table II). This variation may be attributable to the distinct planting density, tree-form and CV at each site (Table I). Wright et al. (2005) reported that expressing fruit numbers relative to CV rather than TCSA gave a better explanation for discrepancies between sites. In addition, an analysis of covariance of fruit mass showed CV to be a significant ($P \leq 0.048$) covariate (data not shown).

The CVs were larger at sites 1 and 3 in 2004 compared with 2003 (Table I; statistical analysis not shown), which was probably due to tree selection. Although the TCSAs did not differ between years, the fruit-canyon densities were substantially lower in 2004 than in 2003. When both years were compared, using fruit-canyon densities, they exhibited similar trends (Figure 2A).

Weather may have influenced fruit mass in at least two ways. Poor pollination conditions during the period of full-bloom naturally thinned the fruit. Since there were fewer fruit to remove, more lateral fruit and multiple fruit clusters were left on the tree, possibly reducing the effect that hand-thinning 50 DAFB had on increasing fruit mass, (Westwood et al., 1967). In addition, CHUs at 42 DAFB in 2003 were 26% higher than in 2004.

**Figure 1**: Linear regression analyses (excluding controls), for each of three experimental sites, between crop-load (fruit cm$^{-2}$ TCSA; x) and mean fruit mass (y) for combined data from 2003 and 2004. Site 1; $y = -9.8x + 218.4; r^2 = 0.64$. Site 2; $y = -17.8x + 290.6; r^2 = 0.90$. Site 3; $y = -10.2x + 265.2; r^2 = 0.75$.

**Figure 2**: Quadratic relationships between fruit-canopy density (excluding controls; expressed as fruit m$^{-3}$ CV) on a log scale (x) and (in Panel A) mean fruit mass (in g; y) or (in Panel B) mean percentage red fruit colour (y) in 2003 (open circles, dotted lines) and in 2004 (closed circles, solid lines). Regression line equations in Panel A are: (2003)$y = 0.00587 x^2 - 1.99x + 275.2; R^2 = 0.89$; and (2004)$y = 0.00277 x^2 - 1.69x + 257.8; R^2 = 0.65$; and, in Panel B are: (2003)$y = 0.00085 x^2 - 0.317x + 70.7; R^2 = 0.38$; and (2004)$y = 0.00153 x^2 - 0.396x + 75.7; R^2 = 0.32$. 

**FIG. 1**

Linear regression analyses (excluding controls), for each of three experimental sites, between crop-load (fruit cm$^{-2}$ TCSA; x) and mean fruit mass (in g; y) for combined data from 2003 and 2004. Site 1; $y = -9.8x + 218.4; r^2 = 0.64$. Site 2; $y = -17.8x + 290.6; r^2 = 0.90$. Site 3; $y = -10.2x + 265.2; r^2 = 0.75$.

**FIG. 2**

Quadratic relationships between fruit-canopy density (excluding controls; expressed as fruit m$^{-3}$ CV) on a log scale (x) and (in Panel A) mean fruit mass (in g; y) or (in Panel B) mean percentage red fruit colour (y) in 2003 (open circles, dotted lines) and in 2004 (closed circles, solid lines). Regression line equations in Panel A are: (2003)$y = 0.00587 x^2 - 1.99x + 275.2; R^2 = 0.89$; and (2004)$y = 0.00277 x^2 - 1.69x + 257.8; R^2 = 0.65$; and, in Panel B are: (2003)$y = 0.00085 x^2 - 0.317x + 70.7; R^2 = 0.38$; and (2004)$y = 0.00153 x^2 - 0.396x + 75.7; R^2 = 0.32$. 

(Environment Canada, 2005). Studies have shown that higher CHUs during this early period can be positively correlated with fruit mass at harvest (Bergh, 1990; Zhang and Thiele, 1992). However, the effect of weather on fruit mass was not assessed and was beyond the scope of this experiment.

**Fruit yield**

Fruit adjustment treatments resulted in differences in yield between the untreated controls and the other treatments, and also between each of the crop-load adjusted treatments (Table II). The increase in individual average fruit mass that accompanied the lowest crop-load adjusted treatments (i.e., 3 fruit cm$^{-2}$ TCSA) did not compensate for the reduction in yield (kg cm$^{-2}$ TCSA) that arose from the lower number of fruit for any treatment in this experiment. This is a common compromise, demonstrated in several thinning experiments (Forshey, 1986; Awad et al., 2001). Analysis of covariance of yield found CV to be a significant covariate ($P < 0.001$), which confirmed that larger CVs result in larger yields (data not shown). In the crop-load adjusted treatments (3, 6 or 9 fruit cm$^{-2}$ TCSA), larger yield was more likely to be the result of an increase in average individual fruit mass. In the untreated controls, larger yields corresponded to greater numbers of fruit.

**Fruit colour**

Improvements in fruit colour (% red skin colour) were inversely proportional to crop-load and yield (Table II). Greener background fruit colour in the highest crop-load treatment (i.e., 9 fruit cm$^{-2}$ TCSA) did not compensate for the reduction in yield (kg cm$^{-2}$ TCSA) that arose from the lower number of fruit for any treatment in this experiment. This is a common compromise, demonstrated in several thinning experiments (Forshey, 1986; Awad et al., 2001). Analysis of covariance of yield found CV to be a significant covariate ($P < 0.001$), which confirmed that larger CVs result in larger yields (data not shown). In the crop-load adjusted treatments (3, 6 or 9 fruit cm$^{-2}$ TCSA), larger yield was more likely to be the result of an increase in average individual fruit mass. In the untreated controls, larger yields corresponded to greater numbers of fruit.

**Return bloom**

Observational data suggest that initial bloom, as well as weather and crop-load-related effects (see above), were factors in determining return bloom (RB). The RB in 2004 was $< 10\%$ of the original bloom at the three sites in 2003. Blossom density in 2003 was 26.2 blossom clusters cm$^{-2}$ TCSA, while the RB at the same sites and trees in 2004 was 2.0 blossom clusters cm$^{-2}$ TCSA. The RB in 2005 was $> 70\%$ of the original bloom at the three sites in 2004. Blossom density in 2004 was 18.3 blossom clusters cm$^{-2}$ TCSA, while RB at the same sites and trees in 2004 was 13.0 blossom clusters cm$^{-2}$ TCSA. There were no significant RB differences between treatments (data not shown). Fruit removal at 50 DAFB, compared with blossoming thinning, has been reported to yield fewer blossoms in the year following treatment (Koike et al., 2003).

**CONCLUSIONS**

This study demonstrates that apple fruit quality increased with lower fruit numbers on the tree, resulting in a lower overall fruit yield. Individual fruit size (mass) was more highly negatively correlated with crop-load than with percentage red fruit colour. Manually adjusting the crop-load at 50 DAFB did not encourage greater RB compared to untreated control trees, and did not markedly alter the strong tendency of ‘Honeycrisp’™ trees to become biennial bearing. In general, the highest fruit quality occurred at 3 or 6 fruit cm$^{-2}$ TCSA. Nonetheless, crop-load recommendations must be site-specific as they are influenced by planting density, tree form and training systems which vary widely in the commercial apple tree industry.

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REFERENCES


