Effect of Blossom Density and Crop Load on Growth, Fruit Quality, and Return Bloom in ‘Honeycrisp’ Apple

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Abstract. From 2003 to 2006, the blossom level and crop load of ‘Honeycrisp’ apple (*Malus × domestica* Borkh.) trees on M.26 rootstocks were adjusted to improve fruit quality and return bloom. The treatments consisted of manually removing flower clusters to 50, 100, and 150 per tree, then at ≈ 50 d after full bloom, the crop load was adjusted to 3, 6, and 9 fruit/cm² trunk cross-sectional area (TCSA), respectively. All flower and crop load adjustment significantly increased TCSA and canopy volume compared with the control. Classic biennial bearing was observed on the untreated control trees and those thinned to 150 blossom clusters per tree and 9 fruit/cm² TCSA and was mitigated for trees with 50 and 100 blossom clusters followed by crop load adjustment to 3 and 6 fruit/cm² TCSA, respectively. Fruit color the “on” year was always lower on the control trees; no difference was found in the “off” year. The treatments increased fruit weight proportional to crop load except for the 2004 “off” year. This study illustrates that for trees with ≈ 1 m³ canopy volume, the combined effects of blossom and crop load adjustment to 100 blossom clusters/tree followed by fruitlet adjustment to 6 fruit/cm² TCSA and below will induce consistent annual production for ‘Honeycrisp’.

‘Honeycrisp’ is a popular new apple cultivar in the premium fresh-fruit marketplace (Rosenberger et al., 2004). Because of the high returns for ‘Honeycrisp’ in the North American markets, Nova Scotia growers are interested in learning how to efficiently manage this cultivar in their region (Nichols and Wright, 2003). The cultivar is hardy and responds well to the more northerly climates (Luby and Bedford, 1990). Although developed in Minnesota and described as a good annual cropper requiring no flower thinning, ‘Honeycrisp’ has exhibited an extreme propensity for overcropping resulting in biennial bearing (Crassweller et al., 2005; Embree and Nichols, 2005; Robinson and Watkins, 2003).

Biennial bearing is the tendency of a cultivar to cycle between a full (“on”) crop year and a minimal (“off”) crop year resulting in inconsistent fruit quality and quantity (Monselise and Goldschmidt, 1982). Biennial bearing can be controlled to some extent by managing crop load in the “on” year, but results vary with cultivar (Schwallier et al., 2006; Singh, 1948). Research has shown that blossom thinning is more effective than fruitlet thinning alone to increase the potential for return bloom (Byers, 1997; Johnson, 1995; Preston, 1954; Singh, 1948; Tromp, 2000), stimulate tree growth, and increase fruit size (McArtney et al., 1996). For many cultivars, the optimal crop load is between 5 and 6 fruit/cm² trunk cross-sectional area (TSCA) (Robinson and Watkins, 2003), but this varies with cultivar and depends on many factors, including spur habit and tree vigor (Singh, 1948).

Managing blossom density and crop load to control the strong biennial nature of this cultivar is one of the greatest challenges for ‘Honeycrisp’ producers. To meet this challenge, we evaluated the impact of adjusting blossom density and subsequent crop load on growth, fruit quality, and return bloom.

Materials and Methods

Experimental site and design. The plot was located in Morristown in the Annapolis

Valley of Nova Scotia, Canada (45°03′00N; 64°46′00W). The ‘Honeycrisp’ trees were planted in 1996 on ‘M.26’ rootstocks. Trees were planted 1.5 m within rows and 4.5 m between rows. The 16 trees were chosen based on bloom density throughout the tree in 2003. Soil type is described as the Morristown series as a very dark grayish brown loam; fine, subangular blocky structure; friable with some shale fragments and pH 4.9 (Cann et al., 1965). The orchard floor was sod-covered with a 1.2-m herbicide strip and no supplemental irrigation was used.

Tree growth. Canopy volume (CV) was calculated using a geometrical model that accounts for the specific contours in shape of each tree ($CV = [(1/4) \pi a b h] / [m(x) + m(y) + 1]$) (Wright et al., 2006b) in which *a* is the width of the tree parallel to the row at 75% of the canopy height, *b* is the width of the tree perpendicular to the row at 75% of the canopy height, *h* is canopy height, *m* accounts for the shape contour of the tree, *x* is the width of the tree base parallel to the row, and *y* is the width of the tree base perpendicular to the row. The TCSA of each tree was calculated from the circumference measured 30 cm above the graft union.

Blossom cluster density and crop load. Each year, in late May, all blossom clusters on each tree were counted. Blossom density was calculated by dividing the number of blossoms by the TCSA. Each tree was ranked according to blossom density at 80% bloom and then allocated to one of four replicate blocks based on blossom density. Using a randomized blocking system, treatments including an untreated control, 50, 100, or 150 blossom clusters/tree with ≈ 1 m³ of canopy volume were assigned to individual trees within each block so that each treatment contained four trees.

Blossom clusters were removed by hand to the previously mentioned treatment densities at 80% full bloom and distributed evenly over the whole tree. After natural fruitlet drop at 50 d after full bloom (DAFB), the remaining fruit were adjusted to the crop load treatments 3, 6, or 9 fruit/cm² TCSA on the trees with 50, 100, and 150 blossom clusters/tree, respectively.

Fruit weight and quality. The fruit was harvested when the background color changed from green to yellow, which occurred ≈ 120 DAFB. The fruit was stored at 2 °C for 20 d, and then removed from storage and allowed to equilibrate to room temperature. The weight and percent total surface showing a red–orange blush was recorded.

Statistical analysis. The data were analyzed using the analysis of variance procedure of the statistical program Genstat 5 (Genstat 5 Committee, 1993). TCSA was used as a covariate to normalize the blossom cluster calculations.

Because a significant effect was found for some treatments during the trial, Tukey studentized range test on the means for each treatment was performed on the crop load and blossom cluster data, whereas Bonferroni multiple comparisons were performed on the

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apple weight data using an error rate of $\alpha = 0.05$ to determine which treatments were significantly different (SAS Institute, 1996).

Results and Discussion

Tree growth. Linear regression analysis demonstrated a treatment effect on the TCSA change over time (Fig. 1). Eighty-four percent of variability in TCSA was accounted for by the 3 fruit/cm² TCSA, 63% by 9 fruit/cm² TCSA, 61% by 6 fruit/cm² TCSA, and 49% by the control. Only in 2006 was there a significant difference between the treatments for the TCSA ($P = 0.022$). Some studies in the past have had difficulty linking a decrease in TCSA with increased crop load because of the many variables associated with cropping and tree growth, including cultivar and root-stock, age of trees, environmental and climatic factors, pruning regime, and sampling years (Rogers and Booth, 1964; Webster and Brown, 1980). However, in a more controlled study of young trees, Maggs (1963) showed that blossom removal doubled the TCSA compared with nonthinned trees. Byers (2003) states that total blossom removal of spur 'Rome' trees increased shoot growth 52% and trunk circumference 47%.

All thinning treatments promoted a significantly larger canopy volume in 2006 than the control trees ($P = 0.02$) (Fig. 2). In this 4-year study, canopy volume increased 56%, 69%, and 70% for the control, 3 fruit/cm² TCSA, and 70% for the control, 3 fruit/cm² TCSA, and both the 6 and 9 fruit/cm², respectively (Fig. 2).

The results indicate that repeat adjustment of flower and crop load below 150 blossoms/tree and 9 fruit/cm² TCSA will increase tree vigor. Other studies have also shown that shoot growth is inversely affected by crop load (Avery, 1969, 1970; Maggs, 1963). However, Rogers and Booth (1964) found a significant negative correlation between crop load and the following year shoot growth, but not necessarily the current year shoot growth. In the current study, canopy volume was only measured at the beginning in 2003 and the end in 2006 and therefore we cannot draw any conclusions whether current year thinning or previous year thinning is the main stimulator of vegetative growth.

Crop load. In 2003 and 2005, the 'Honeycrisp' trees in this trial were in an "on" year and thus the crop load at harvest accurately reflected the thinning treatments of 3, 6, and 9 fruit/cm² TCSA (Fig. 3). During the "off" years when there was sufficient fruit set, the crop load was also adjusted to these levels. A pattern of biennial cropping remediation can be seen by studying the response for each treatment between the "on" and "off" years (Fig. 3). The nonthinned untreated control trees displayed extreme biennialism with practically no fruit in the 2004 and 2006 "off" years, and even the trees thinned to 9 fruit/cm² TCSA showed the tendency to biennialism. At 6 and 3 fruit/cm² TCSA, a more consistent annual production was achieved.

Fig. 1. Linear regression analysis of the trunk cross-sectional area (TCSA) over the 4-year trial for each experimental thinning treatment.

Fig. 2. Effect of flower and crop load adjustment on 'Honeycrisp' tree canopy volume for 2003 and 2006 ($P < 0.05$, $n = 4$).

Fig. 3. Average 'Honeycrisp' crop load for each treatment from 2003 to 2006. Bars with different letters are statistically different within year by Tukey multiple comparison analysis ($P < 0.05$, $n = 4$).

Fruit quality. Fruit color was dramatically affected by the heavy cropping of fruit on the trees. During the 2004 and 2006 "off" years, there was no appreciable difference in fruit color (Table 1). During the 2003 and 2005

"on" years, a difference is seen between the treatments and especially in the control trees, which were overcropped and had greatly reduced coloration ($P < 0.0001$ and $P = 0.002$, respectively).

Similar to these results, Wright et al. (2006a) found that fruit color in 'Honeycrisp' was inversely proportional to crop load and yield when trees were manually adjusted (3, 6, and 9 fruit/cm² TCSA). 'Honeycrisp' can produce high-quality apples when crop load levels are optimum. Excessive crop loads have been reported to reduce color, fruit firmness, total acidity, soluble solids, and starch (Robinson and Watkins, 2003). Robinson and Watkins (2003) suggest that poor fruit color may be the result of less assimilate flow to each fruit. Their suggestion is also supported by the multiple site study in Wright et al. (2006a). These previous studies and the current findings support the use of chemical bioregulators to adjust current year crop loads for the production of high-quality 'Honeycrisp' apples (Embree and Nichols, 2005).

Treatments had a significant effect on the fruit weight in each of the 4 years of this study. In the 2004 "off" year, the magnitude of the difference between the crop load-adjusted trees and the control trees was less because of the low numbers of fruit on the control trees (Fig. 4). However, for the control trees, although the crop load was very low in the "off" years of 2004 and 2006, fruit were on average smaller than any of the three treatments that adjusted flowering and crop load.

The low fruit weight displayed by the control trees in this study and subsequent fruit weight increase in the thinned trees has been seen in previous 'Honeycrisp' studies (Embree and Nichols, 2005; Robinson and Watkins, 2003; Schupp, 2003; Wright et al., 2006a). Fruit size is determined by cell number, cell size, and intercellular space (Goffinet et al., 1995). However, cell number, which is determined early in apple development, accounts for most of the variation in fruit size (Pearson and Robertson, 1953), and it can be influenced by the previous year's crop load and may reduce the number of cells in the flower receptacles if it is excessive (Bergh, 1985). Therefore, the destined size of an apple may be determined by the current as well as previous year resources. Nonetheless, this study clearly shows the value of adequate crop load adjustment for increasing size in 'Honeycrisp'.

Return bloom. Return bloom was not significantly affected by treatments in the 2005 "on" year, but treatments did significantly affect the return bloom in the "off" years, 2004 and 2006 ($P < 0.001$ and $P < 0.01$,

respectively) (Fig. 5). The propensity to increase the "on" years is almost double with a mean of ≈ 300 blossoms/tree in 2004 and over 500/tree in 2006. The dramatic effect of cropping on biennial bearing is seen in the control trees in which return bloom is completely polarized (Fig. 5).

In the 2004 "off" year, trees in the control treatment had significantly fewer blossom clusters than those whose crop load had been adjusted to 3 and 6 fruit/cm² TCSA trees ($P < 0.0001$ and $P = 0.003$) and also had more blossom clusters than the trees with 9 fruit/cm² TCSA.

In 2006, the 3 and 6 fruit/cm² TCSA trees of 2005 displayed significantly more blossom clusters than the control trees ($P = 0.008$ and $P = 0.005$, respectively); however, none of the trees with adjusted flowers or fruit were significantly different nor were the trees with 9 fruit/cm² TCSA significantly different from the control.

These results show that reducing the crop to 6 fruit/cm² TCSA will significantly increase the number of blossom clusters above a nonthinned tree during the "off" years. The presence of fruit on the tree the previous season is known to be antagonistic to flower formation and is thought to be the result of hormones produced by the seeds (Chan and Cain, 1976). Many theories abound regarding the triggers of flower bud formation in pome fruits, and it is highly likely that a mixture

of both physical and physiological factors contribute (Tromp, 2000). The results of this study and Wright et al. (2006a) suggest that both blossom and crop load reduction below certain levels alter the plant resource requirements sufficiently to increase fruit bud initiation the season after adjustment.

Conclusion

Blossom and fruitlet thinning are two of the most important tools apple growers can use in their attempts to affect biennial bearing fruit quality. Adequate flower and fruit thinning improves fruit characteristics such as color and size that are important to the fresh market. Results from the present study indicate that production of 'Honeycrisp' could be optimized for trees ranging in TCSA from 16 to 35 cm² by adjusting blossom density to 100 blossom clusters/tree followed by a crop load adjustment to ≈ 6 fruit/cm² TCSA. This supports a consistent crop load each year, barring any unforeseen environmental factors. Further research is warranted to more accurately quantify the individual and combined relationships between blossom and crop load on maximum yield and return bloom.

This study used hand-thinning to adjust blossom numbers and crop load, which is very time-consuming and costly. Commercially, blossom thinning using approved chemical applications would be more practical. There

Fig. 4. Average 'Honeycrisp' fruit weight for each treatment from 2003 to 2006. Bars with different letters are statistically different within year by Bonferroni multiple comparison analysis ($P < 0.05$).

Fig. 5. Effect of adjusting flower and fruit levels on 'Honeycrisp' blossom clusters per tree before manual adjustments the year of treatment. Bars with different letters are statistically different within year by Tukey multiple comparison analysis ($P < 0.05$, $n = 4$).

Table 1. Average percent fruit color for all Honeycrisp apples on each tree for each thinning treatment for each year of the trial.

Treatment	Yr			
	2003	2004	2005	2006
Control	33	64	16	32
3 fruit/cm ² TCSA	63	56	55	38
6 fruit/cm ² TCSA	67	54	47	38
9 fruit/cm ² TCSA	54	53	34	40
SEM	3.01	4.49	5.22	7.42
F p	<0.0001	1.00	0.002	1.00

TCSA = trunk cross-sectional area.

are a limited number of approved blossom-thinning chemicals available to producers, and research into more environmentally friendly thinning agents is still in its early stages. More work is needed to determine optimal rates for existing products and to test new products to provide accurate blossom thinning.

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