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Multiple Season-long Sprays of Ethephon or NAA combined with Calcium Chloride on 'Honeycrisp' Apples: I. Effect on Bloom and Fruit Quality Attributes

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Abstract:

'Honeycrisp' apple trees are highly prone to biennial bearing and predisposed to bitterpit. The hypothesis that tank mix sprays of ethephon (ETH), naphthaleneacetic acid (NAA), and 1-aminocyclopropane carboxylic acid (ACC) combined with calcium chloride (CaCl_2) can mitigate these production problems was tested in a 3-y study. Mature 'Honeycrisp' trees were treated with either three or six summer applications of 150 mg L^{-1} ETH or 5 mg L^{-1} NAA, all tank mixed with and without CaCl_2 , or two or five applications of 150 mg L^{-1} ACC (without CaCl_2). Treatments were applied at 10-d intervals and initiated between 21-26 June. All treatments had little effect on enhancing return bloom of 'Honeycrisp'. NAA, ETH, and CaCl_2 all influenced fruit maturity and quality at harvest to varying degrees, and across years. Fruit treated with NAA were firmer compared with untreated fruit in two of three years, whereas overall, fruit treated with six sprays of ETH had lower fruit firmness and were more mature. NAA had less influence on fruit quality attributes at harvest than did ETH, and decreased pre-harvest fruit drop (PFD). PFD increased with ETH in one of two years, whereas ACC and NAA both decreased PFD in one of two years. Overall, ETH and NAA, with or without CaCl_2 , had significant but inconsistent effects on fruit

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quality and maturity, all dependent on the year and number of applications. Adding CaCl_2 decreased fruit firmness in two of three years.

Keywords: Ethrel, 2-chloroethylphosphonic acid, naphthaleneacetic acid (NAA)

Introduction

Producers of 'Honeycrisp' apples (*Malus domesitca* Borkh) face several production challenges, including biennial bearing (BB), susceptibility to low fruit calcium (Ca) (Ferguson and Watkins, 1989), overall weak vegetative growth, and significant post-harvest storage disorders. BB is a physiological phenomenon characterized as a repetitive cycle of heavy flowering/fruiting followed by a light year of flowering/fruiting, referred to as 'on' and 'off' years, respectively. Several researchers have reviewed this topic (Hoblyn et al., 1936; Jonkers, 1979; Monselise and Goldschmidt, 1982) and apples are not unique to BB. Olive (*Olea europaea* L.), citrus (*Citrus* spp.), avocado (*Persea americana* Mill.), mango (*Mangifera indica* L.), pear (*Pyrus communis* L.) as well as some tree nut species (Monselise and Goldschmidt, 2011) are prone to BB.

BB reduces orchard profitability because of its effects on fruit size, colour, fruit quality, and orchard productivity (Wright et al., 2006). Fruit from light-cropping trees can be more prone to bitter pit, as a consequence of their larger fruit size, resulting in marketing and storage losses (Fallahi et al., 1985, Ferguson and Watkins, 1989). Moreover, cumulative yields from BB apple cultivars are often

lower than cultivars which do not display an alternate cropping tendency (Jonkers, 1979).

BB is the result of the imbalance between the proportion of vegetative and fruiting spurs. In the 'off' year of the cycle, most developing axillary meristems produce mixed buds with both leaf and flower primordia for the following year, whereas in the 'on-crop' year, most of the buds produce vegetative buds with leaf primordia only. Spurs that carry one or more fruit are less likely to produce flowers the following year (Dennis and Neilsen, 1999), a trait that all apple cultivars exhibit to a greater or lesser extent. In the 'on' year, floral initiation is reduced, resulting in a lower return bloom and reduced number of fruit per tree in the 'off' year. In contrast, during the 'off' year, floral initiation is higher, resulting in greater inflorescence and number of fruit per tree in the 'on' year. This fluctuation has largely been attributed to effects of crop load and hormonal inhibitors produced by seeds (i.e. gibberellins) (Chan and Cain, 1967; Dennis and Neilsen, 1999; Schmidt et al., 2009; Schwallier et al., 2006). Environmental events such as late spring frosts, prolonged droughts, and temperature extremes can also induce BB in regular cropping trees via their effect on crop load reduction (Monselise and Goldschmidt, 1982).

Aside from environmental factors, individual cultivars are known to vary in their propensity towards BB. Cultivars such as 'Idared' (Jonkers, 1979), 'Gala' and 'Empire' (J. A. Cline, personal knowledge) normally display little variation in

cropping, whereas 'Honeycrisp' (Cline and Gardner, 2005), 'Northern Spy' (Dennis, 1998), 'Braeburn', 'Delicious', 'Fuji', 'Golden Delicious' (McArtney et al., 2007), and 'York' (McArtney et al., 2013) are cultivars which display a greater tendency towards BB. The physiological explanation for why some apple cultivars exhibit less BB is not fully understood.

The management of crop load via chemical thinning has been a successful approach for alleviating BB in many cultivars (Aldrich, 1932). However, despite advances in thinning compounds and earlier application timings, BB continues to be problematic in 'Honeycrisp'. As a result, alternative strategies of controlling BB of 'Honeycrisp' are particularly of interest to growers, especially because it has such a profound effect on orchard productivity, tree growth, and profitability. Specific uses of plant bioregulators (PBR) offer promise for altering flowering and cropping habits.

Several PBR compounds, including paclobutrazol (El Hodairi and Canham, 1990), daminozide (Jones et al., 1989), triodobenzoic acid (Bukovac, 1968), NAA (Harley et al., 1958), and ethephon (ETH) (Williams, 1972) have enhanced flowering in apple trees the year following application. Several studies report enhanced flowering in bearing apple trees from foliar applications of ETH at concentrations ranging from 150 to 1000 mg·L⁻¹, with treatments varying by number of applications, application dates, and cultivars (Bukovac et al., 2006; McArtney et al., 2007; McArtney et al., 2013; Schmidt et al., 2009; Williams,

1972). Similar results have been obtained with NAA at concentrations of 4 to 5 mg·L⁻¹, also with varying numbers of applications and application dates (McArtney et al., 2007; McArtney et al., 2013). Spray programs of ETH or NAA are recommended to enhance flowering in bearing and non-bearing apple trees in tree fruit production guides (e.g. Cowgill and Autio, 2009; Schwallier, 2006; Washington State University Extension, 2009) but few publications have directly compared the efficacy of these two growth regulators on 'Honeycrisp.'

The application of PBR sprays to promote flower initiation during the 'on' year can enhance return bloom in the 'off' year, when poor bloom would otherwise be expected. ETH application at 200 mg·L⁻¹ applied twice or three times during the 'on' year has effectively promoted return bloom and reduced the effects of BB over multiple seasons in bearing 'Delicious' trees (Bukovac et al., 2006). By promoting additional crop load in the 'off' year, excessive 'on' year crop load has also been subsequently reduced (Bukovac et al., 2006), further alleviating the severity of BB. Byers (1993) found that 1000-1500 mg/L ETH applied to 'Delicious' greatly increased flowering and fruit set the following season, and that bloom sprays were more effective than late June or July applications. However, the return bloom flowering data were confounded by the fact that ETH can cause significant fruit abscission and reductions in crop load. Jones et al. (1989) found that ETH applied at 450 or 750 mg/L increased return bloom the year following application, while concomitantly reducing shoot growth the year of application. In 'Delicious' trees, the authors reported a negative linear relationship between

reduced shoot growth—induced by the PBRs ETH and daminozide—and return bloom (Jones et al., 1989). Fallahi et al. (1997), found that application of hydrogen cyanimide (Dormex) at 2580 mg L⁻¹ significantly reduced fruit set in the year of application but increased return bloom and fruit set in the following year in 'Rome Beauty' apple.

Another compound with the potential to enhance return bloom is 1-aminocyclopropane carboxylic acid (ACC). ACC plays an important role in the biosynthesis of ethylene (Kende, 1993, Yang and Hoffman, 1984) and is synthesized by the enzyme ACC synthase from methionine and converted to ethylene by ACC oxidase (Kende, 1989). There are no studies in the literature that used ACC to enhance the return bloom of apple, and given that it promotes the production of ethylene *in planta* once absorbed, it may be more effective than ETH in mediating ethylene levels.

Impacts of such bloom enhancement sprays on fruit maturity indices are variable. Early- to mid-season applications, applied within 90 days after full bloom (DAFB), of both ETH (Bukovac et al., 2006) and in most cases NAA (McArtney et al., 2007), have been reported to have little or no effect on fruit maturity. Applications of ETH at 450 mg·L⁻¹ in the month before harvest have resulted in reduced starch content, lower flesh firmness, and enhanced ethylene production of 'Gala Gala' at harvest and following storage, indicating advanced maturity (Drake et al., 2006). Application of NAA in the month prior to harvest has also been

demonstrated to lower flesh firmness and to advance maturity of 'Marshall McIntosh' apples (Stover et al., 2003).

Few previous studies have aimed to enhance the flowering of bearing 'Honeycrisp'; however, the reported success of ETH and NAA treatments to enhance bloom of other apple cultivars merits its investigation for use on 'Honeycrisp.' The objective of this study was therefore to determine the effect of multiple season-long foliar ETH and NAA application on bearing 'Honeycrisp' apple trees and on fruit quality and return bloom.

Materials and Methods

An experiment, repeated over three growing seasons, was conducted to investigate the response of 'Honeycrisp' apple trees to summer applications of the floral-promoting PBRs NAA and ETH on fruit quality and return bloom. In addition, the benefit of including a tank mix spray with or without calcium chloride for bitter pit control and enhanced fruit tissue calcium levels was tested and reported elsewhere (Cline, 2018 Part II).

'Honeycrisp' apple trees on M.9 T337 (1.8 x 4.5 m), planted in 2000 at the University of Guelph, Simcoe Research Station, Simcoe ON (42° 51' 00" N, 80° 16' 00" W), and trained to a vertical axe were used for this experiment. The soil profile consisted of a mixture of Fox and Watford soil series, which was comprised mainly of glaciolacustrine sands modified by wind sorting with good to

rapid drainage (Hohner and Presant, n.d.). A 1.0-m wide strip down the row of the trees was kept free of weeds using 1% (v/v) glyphosate herbicide. Crop load was managed using 1000 mg/L carbaryl (Sevin XLR), followed by hand thinning after physiological drop to ensure uniform crop loads. In 2009 and 2013, the following five foliar treatments were applied: i) untreated control; ii) three applications of 150 mg L⁻¹ ETH (Ethrel, Rhône Poulenc, ON) applied at 10-d intervals starting 21-26 June; iii) six applications of 150 mg L⁻¹ ETH applied at 10-d intervals starting 21-26 June; iv) three applications of 5 mg L⁻¹ NAA (Amvac, Newport Beach, CA) applied at 10-d intervals starting 21-26 June; and v) six applications of 5 mg L⁻¹ NAA applied at 10-d intervals starting 21-26 June. In addition, treatments 2 through 5 were each tank mixed with 6 g L⁻¹ food-grade calcium chloride (94% anhydrous CaCl₂, Occidental Chemical Corp. Ludding, MI), resulting in a total of nine treatments (Table 1). In 2014 only, additional treatments of 150 mg L⁻¹ 1-aminocyclopropane carboxylic acid (ACC, VBC-30445; Valent BioSciences, Libertyville, IL) were applied (without calcium chloride) a total of two (27 June, 10 July) and 5 times as indicated in Table 1. All sprays included 0.05% (v/v) Regulaid organo-silicone surfactant to improve wetting and uptake (Kalo Industries, Overland Park, KS).

Treatments were applied during calm wind conditions using a commercial air blast sprayer (GB Irrorazione Diserbo, Model Laser P7, Italy) at 1379 kPa, 388 L/ha, which equated to tree row volume (TRV) pesticide dilute (Sutton and Unrath, 1988). The sprayer was equipped with five nozzles per boom (side) and a large axial fan to move the spray into the canopy. To minimize treatment

interference caused by spray drift, experimental units were separated by at least two guard trees, considered sufficient based on our previous research (Arseneault, 2016). Treatments were arranged in a randomized complete block design and consisted of two trees per experimental unit. All orchards were managed according to standard practices for Ontario (OMAFRA, 2009).

Tree growth was determined by measuring trunk circumference at 30 cm above the soil line in the spring and fall of each year. Trunk cross-sectional area (TCSA) was then calculated from the trunk circumference.

In 2009, flowering was assessed individually by three individuals, who rated bloom on the entire tree using a 4-point scale where 0 represented no bloom, and 1-3 represented low, medium, and high bloom, respectively adopted from Marini (2004). To improve upon this method, a more refined 6-point scale was used in subsequent years, where 0 represented no bloom and 1-5 represented very low, low, medium, high, and very high bloom respectively. Fruit were harvested based on local recommended starch-index values and colour. The number and weight of fruit harvested per tree were recorded and the crop load, yield efficiency, and mean fruit weight were determined. Crop load was determined by dividing the total number of fruit harvested per tree by its TCSA. Yield efficiency was calculated by dividing the total yield by the TCSA. Mean fruit weight was calculated by dividing total yield by the number of fruit from each tree. In 2014 only, fruit drop was monitored on the second tree of each experimental unit because it appeared to be particularly severe that year.

Fruit quality was assessed on 15 fruit per tree for each experimental unit by measuring fruit ethylene evolution, fruit colour, firmness, soluble solids, and titratable acidity. These assessments were done at harvest time each year.

Ethylene evolution was evaluated with the static headspace method (Sharma et al., 2012). The 15-fruit samples were placed in 11-L plastic pails with airtight lids (Model 61996; IPL, Saint-Damien, Quebec, Canada). Each of the sealable lids (Model 63475; IPL, Saint-Damien, Quebec, Canada) contained a hole with a 10-mm rubber septum allowing air from within the pails to be sampled using a syringe when required. The 15 fruit were allowed to respire in the pails for 24 h before a 2.0-mL gas sample was drawn using a 25 gauge hypodermic needle. This was then injected into a gas chromatograph (Model 8610C; SRI Instruments, Torrance, CA) calibrated with 5 ppm standard ethylene gas (Linde Industrial Gases Canada, Mississauga, ON, Canada). The gas chromatograph contained a 2-m 80-100 mesh HayeSep D pack column (70°C) and a flame ionization detector (150°C). Hydrogen was used as the carrier gas with a flow rate of 5 mL/min⁻¹, and air and hydrogen were used as the combustion gases, with flow rates of 5 mL/min⁻¹ and 10 mL/min⁻¹, respectively. The rate of ethylene evolution was represented as nL (C₂H₄) g fruit fresh weight⁻¹ hr⁻¹.

Fruit blush and ground colour were quantified using a colorimeter (Model CR-400; Konica-Minolta, Tokyo, Japan) and expressed using the international standard CIELAB colour coordinates: L* (lightness: intensity from black to white from values of 0-100), a* (green to red), and b* (blue to yellow). The a* and b* values were converted to C* (chroma: purity where low is faded and high is

vivid), and H^0 (hue angle: similarity to red (0), yellow (60), and green (120)). For consistency, the most colour-intense areas were measured to represent the blush and ground colour.

Fruit firmness was measured twice on each fruit using an electronic penetrometer (Fruit Texture Analyzer Model GS-14; Güss Manufacturing, Strand, South Africa). An 11-mm stainless steel diameter blunt probe was inserted at a rate of 5 mm sec⁻¹ to a depth of 8.9 mm, and the peak force recorded. Measurements were taken on opposite sides of the fruit after a ~2-mm thick tangential section of peel (1.5 to 2.0 cm in diameter, 1 to 2 mm thickness) was sliced from the equator of the fruit. The mean of these two measurements was used in subsequent data analysis.

Each fruit was also assigned a starch-iodine index value indicative of starch hydrolysis and hence maturity level. Each fruit was cut in half at the equator to dip one cut surface in an iodine solution. Several minutes following exposure to the solution, the percentage and pattern of stained flesh was observed and a value was assigned by comparing with the Cornell generic starch-iodine index chart for apples (Blanpied and Silsby, 1992). The starch index ratings ranged from 1 to 8, where 1 indicated high starch concentration, and 8 indicated the absence of any starch.

One-sixteenth of each remaining, unaltered fruit was placed in a plastic bag, sealed, and then frozen at -20°C. The composite sample was thawed and the

juice extracted using a low-speed juicer (Model 8006; Omega Products Inc., Harrisburg, PA) and the juicer components were rinsed between samples. The soluble solids content (SSC), expressed as °BRIX, was measured using a ~2 mL sample of juice that filled the well of a temperature-compensating digital refractometer (Model Palette PR-32x; Atago, Tokyo, Japan). The sample well was cleaned with distilled water and a Kim wipe (Kimberly-Clark Professional, Irving, TX) between samples. Fruit density and volume were measured on each of the ~100 fruit per tree using water displacement and a top-loading balance. Fruit length-to-diameter (L:D) ratio was determined by measuring the total length and diameter of the 10 fruit, positioned longitudinally and then laterally in a 'V' shaped trough, respectively.

Fruit were assessed for bitterpit, are published in part II of this study (Cline, 2019).

Statistical Analysis

Data were subject to an analysis of variance using SAS ver. 9.4 (SAS Institute; Cary, NC) with a chosen significance level of 5% ($\alpha=0.05$). A mixed analysis model (PROC GLIMM) was used with block as a random effect and treatment as a fixed effect. Plots of residuals were examined to determine whether plots displayed patterns of homogeneity of error variance, according to the methods described by Bowley (2008). Residual plots displaying evident patterns of heterogeneity were transformed (natural logarithm) prior to analysis if transformation improved homogeneity. All data are presented in the original non

transformed values. Single degree-of-freedom contrasts were used to test a number of pre-planned treatment comparisons for each experiment. Contrasts were examined regardless of the outcome of the overall omnibus F-test (Lomax, 2007; Sheskin, 2004). Mean separation using Duncan's Multiple Range Test was used to separate treatment means ($P=0.05$).

Results

Return Bloom

The effect of the treatments on return bloom was inconsistent across years. ANOVA indicated that the treatments did not significantly affect return bloom in the spring following treatment application in 2009; however, the contrasts indicated a significant reduction in return bloom following six sprays of ETH compared with three sprays. ETH did not affect return bloom in 2013 or 2014 (Tables 2–4). In 2013, contrasts indicated a reduction in return bloom following applications of NAA, whereas this was not observed in other years. In 2009 and 2014, the addition of CaCl_2 resulted in a slight but significant increase in return bloom, as indicated by the contrasts, but this effect was not observed in 2013.

Tree Growth, Yield, and Crop Density

According to ANOVA, applications of ETH or NAA, with or without CaCl_2 , did not affect annual TCSA in the fall of the year of application (Tables 2–4). However,

the contrasts indicated a statistically significant increase in TCSA following applications of NAA in 2013 and ETH or ACC in 2014 (Tables 3-4).

The response of the various yield parameters to applications of ETH and NAA with or without CaCl_2 was inconsistent from year to year. Total and marketable yield in 2009 and 2013 were unaffected by applications of ETH or NAA according to the ANOVA (Tables 2–3). In 2014, six applications of ACC significantly reduced total fruit yield compared with the untreated control and reduced marketable yield compared with three sprays of NAA plus CaCl_2 or six sprays of ETH (Table 4). Increasing from three to six sprays of ETH resulted in an increased yield and percent of marketable fruit in 2014 according to the contrasts. Application of NAA reduced the percent of marketable fruit compared with the untreated control in 2013 but not in 2014. The mean weight of marketable fruit was unaffected by the treatments in 2009 and 2013 (Tables 2-3). Although not significantly different from the untreated control according to the mean separation, the contrasts indicated that applications of ACC in 2014 resulted in an increased mean weight of marketable fruit (Table 4). Mean weight of marketable fruit from trees treated with six applications of ACC was significantly higher than fruit treated with six sprays of NAA with or without CaCl_2 .

Crop density was unaffected by the treatments in 2009 and 2013 but was significantly reduced by three or six sprays of ACC compared with the untreated

control in 2014 (Tables 2–4). The contrasts also indicated a significant overall reduction in crop density following applications of ETH in 2014.

Pre-Harvest Fruit Drop (PFD)

PFD was significantly affected by the treatments in 2013 and 2014 (Tables 3-4). In 2013, none of the treatments resulted in significant differences compared with the untreated control, although some differences were evident amongst the other treatments. In 2013, the contrasts indicated an increase in fruit drop with ETH, and three, but not six applications of NAA. In 2014, ETH did not increase PFD, whereas ACC and NAA both decreased it. PFD was unaffected by the addition of calcium chloride in all study years.

Fruit Quality and Ethylene Evolution

Applications of ETH and NAA with or without CaCl_2 had significant but inconsistent effects on fruit quality and maturity at harvest (Tables 5-7). The addition of CaCl_2 to the spray mixture reduced percent blush in 2009 (Table 5) according to the contrasts but this effect was not observed in 2013 (Table 6) or 2014 (Table 7). Applications of NAA did not affect red blush in 2009, but in 2013, three sprays of NAA without CaCl_2 and six sprays of NAA with or without CaCl_2 significantly reduced red blush compared with the untreated control (Table 6). In 2014, six sprays of NAA without CaCl_2 significantly reduced percent red blush

compared with the untreated control. This was supported by the contrasts in all years, which indicated a decrease in red blush following applications of NAA. Increasing the number of sprays of NAA from three to six reduced percent red blush in 2013 but not in 2014. Although there was no indication of an overall effect of ETH applications, increasing from three to six sprays of ETH increased percent red blush in 2013 and 2014, but not in 2009. Applications of ACC in 2014 did not affect percent red blush.

Applications of ETH or NAA with or without CaCl_2 affected starch index values in 2009 and 2013, but not in 2014 (Tables 5–7). In 2009, the starch index was significantly higher following three sprays of NAA plus CaCl_2 , six sprays of ETH with or without CaCl_2 , and six sprays of NAA plus CaCl_2 compared with the untreated control. In 2013, six applications of ETH, with or without CaCl_2 , significantly increased the starch index, whereas three or six sprays of NAA without CaCl_2 decreased the starch index compared with the untreated control. The contrasts indicated a significant increase in the starch index with CaCl_2 or ETH in 2009 and 2013. In 2009, applications of NAA increased the starch index but decreased it in 2013. Increasing from three to six applications of ETH increased the starch index in both 2009 and 2013.

Soluble solids concentration ($^{\circ}\text{BRIX}$) values were significantly affected by the treatments in 2013 and 2014 but not in 2009 (Tables 5-7). In 2013, three

applications of ETH plus CaCl_2 significantly increased soluble solid values compared with the untreated control. The contrasts also indicated that applications of ETH resulted in an overall increase in soluble solids. In 2014, there were few significant differences among the treatments, although applications of ACC increased soluble solids values according to the contrasts.

Titrateable acidity of the fruit was also significantly affected by the treatments in 2013 and 2014 but results were variable from year to year (Tables 6-7). In 2013, none of the treatments resulted in statistically significant differences compared with the untreated control, although there were differences among the other treatments. Increasing from three to six applications of ETH resulted in a significant decrease in titrateable acidity in both 2013 and 2014 according to the contrasts. In 2014, titrateable acidity was significantly lower following six sprays of ETH, with or without CaCl_2 , compared with the untreated control. This was supported by the contrasts, which indicated an overall decrease in titrateable acidity following applications of ETH. Applications of ACC in 2014 resulted in a significant increase in titrateable acidity according to the contrasts.

Treatments did not influence fruit ethylene evolution at harvest in 2013 (Table 6) or 2014 (Table 7). At the time of measurement, ethylene levels ranged from 9 to 20 nL ethylene·g·fruit⁻¹ hr⁻¹, indicating that fruit were in the climacteric stage of maturity.

Treatments had a significant effect on fruit firmness in each year of the study (Tables 5-7). In 2009, six applications of ETH plus CaCl_2 significantly reduced firmness at harvest compared with the untreated control. In 2013 and 2014, six applications of ETH, with or without CaCl_2 , reduced firmness at harvest and post-harvest compared with the untreated control. This is supported by the contrasts, which indicated a significant reduction in firmness when the number of applications of ETH was increased from three to six. In 2014, six sprays of ACC also reduced fruit firmness at harvest and post-harvest compared with the untreated control. The addition of calcium to the spray solution decreased fruit firmness at harvest in 2009 and 2014 but not in 2013. Applications of NAA did not affect fruit firmness at harvest compared with the untreated control in any year according to the ANOVA; however, the contrasts indicated a slight decrease in fruit firmness in 2009 and an increase in 2013 and 2014. In 2013, fruit firmness following fruit storage was significantly higher in fruit receiving six sprays of NAA with or without CaCl_2 . In 2014, fruit firmness was higher in fruit that had received three or six applications of NAA without CaCl_2 compared with the untreated control. This was corroborated by the contrasts, which indicated a significant increase in post-harvest fruit firmness in 2013 and 2014 following applications of NAA. Six applications of ACC in 2014 significantly reduced fruit firmness at harvest and post-harvest compared with the untreated control, but this effect was not observed with three applications of ACC.

Fruit blush colour became lighter, less intense and less red following applications of NAA in 2013 and 2014 (Tables 7-9). Lightness (L^*) values were significantly higher (whiter colour) with six sprays of NAA with or without CaCl_2 in 2013 and with six sprays of NAA without CaCl_2 in 2014. In 2013, chroma (C^*) values were significantly lower (less intense) following three applications of NAA with CaCl_2 or six sprays of NAA with or without CaCl_2 compared with the untreated control, but this effect was not observed in 2014. Six sprays of NAA with or without CaCl_2 in 2013 and six sprays of NAA without CaCl_2 in 2014 resulted in significantly higher (less red) hue angle (h°) values compared with the untreated control. These results were also reflected in the contrasts, which indicated an overall increase in L^* values (in both years), a decrease in C^* values (in 2013 only), and an increase in h° (in both years) with applications of NAA compared with the untreated control. The contrasts also indicated a significant increase in L^* (in both years), a decrease in C^* values (2013 only), and an increase in h° (in both years) when the number of applications of NAA was increased from three to six.

According to the contrasts, fruit ground colour was greener in 2013 and more intense in 2014 with applications of NAA. Hue angle was significantly higher with six applications of NAA without CaCl_2 compared with the untreated control in 2013, whereas NAA applications in 2014 had no effect. The contrasts in 2013 indicated a significant overall increase in h° with NAA compared with the untreated control, and a significant increase with six compared with three applications. Although not significantly different according to the mean

separation, the contrasts indicated a significant overall increase in C^* values with applications of NAA compared with the untreated control in 2014.

Fruit blush colour was largely unaffected by applications of ETH when compared with the untreated control; however, blush colour was more intense with six applications of ETH compared with three in both 2013 and 2014 according to the contrasts. In 2013, six sprays of ETH with CaCl_2 resulted in significantly higher C^* values compared with three sprays of ETH without CaCl_2 . Fruit ground colour was significantly less green following six applications of ETH with or without CaCl_2 compared with the untreated control in both years. This effect is supported by the contrasts, which also indicated significantly lower h° with six applications of ETH compared with three. Although not significant according to the ANOVA or the mean separation, the contrasts in 2013 indicated that ground colour was lighter and less intense with applications of ETH compared with the untreated control. In 2014, six applications of ETH without CaCl_2 resulted in significantly lower C^* values compared with three sprays of ETH with CaCl_2 and the contrasts indicated a significant decrease in C^* values with six sprays compared with three.

Fruit blush colour was not affected by the inclusion of CaCl_2 in the spray solution according to the mean separation; however, the contrasts in 2013 and 2014 indicated a slight increase in intensity and redness with CaCl_2 application. Adding

CaCl₂ to the spray solution did not significantly affect ground colour in either year.

In 2014, applications of ACC resulted in more intense blush colour and more intense and less green ground colour. Chroma values of fruit blush colour were significantly higher with three sprays of ACC compared with the untreated control, and this effect was also supported by the contrasts. Although not significantly different from the untreated control according to the mean separation, the contrasts indicated a significant increase in C* of the ground colour with applications of ACC. Hue angle of the ground colour was significantly lower (less green) with three or six sprays of ACC compared with the untreated control, and six sprays resulted in significantly lower h° compared with three sprays, according to both the mean separation and contrasts.

Discussion

Despite many producers in the industry who are using florigenic PBRs to enhance return bloom, the results of this study indicate that repeat summer sprays of ETH, NAA, and ACC beginning 30–47 DAFB had little effect on enhancing return bloom of ‘Honeycrisp’ the year following application. These data are consistent with Robinson et al. (2009a), who found variable effects of NAA or ETH sprays on return bloom when 3–4 weekly sprays of 5 mg/L NAA or 150 mg/L ETH were applied beginning June 21. However, when these sprays

were combined with early fruitlet thinning sprays, in one year out of three, return bloom was improved with a single spray of NAA or ETH, with no added benefit of additional sprays (Robinson et al, 2009b). In experiments conducted in the southeastern USA on 'Delicious' and 'Golden Delicious,' NAA increased return bloom in six of ten experiments, whereas ETH increased return bloom in four of seven experiments (McArtney et al, 2007). Four biweekly applications of 5 ppm NAA during June and July increased return bloom as effectively as four weekly applications the month before harvest (McArtney et al., 2007). In another study conducted in Michigan on 'Delicious,' 200 mg/L ETH applied at 3, 3 + 6, and 3 + 6 + 9 weeks after full bloom (WAFB) in 'on' years increased flowering in 'off' years by 33% and reduced flowering in 'on' years by 17% compared with the untreated control (Bukovac et al., 2006). The biennial cultivar Fuji has also been reported to respond to multiple sprays of ETH with increased return bloom (Feree and Schmid, 2000). In another study on non-bearing trees of the biennial cultivar Northern Spy, 1500 mg/L ETH applied 5 and 8 WAFB significantly increased flowering the year following treatment, with a greater effect from a higher concentration or a second application (Duyvelshoff and Cline, 2013). However, single or multiple applications of 150 mg/L ETH or 5 mg/L NAA on bearing Northern Spy trees failed to increase return bloom, even when trees were not biennial (Duyvelshoff, 2011). In the current study, CaCl_2 also increased return bloom in two of three years. It is unclear how CaCl_2 improved flower bud initiation and return bloom. One might speculate CaCl_2 influenced tree ethylene levels, but this would need to be confirmed through further study.

Naphthaleneacetic acid or ETH treatments in the 'on' year of a biennial bearing cycle can promote return bloom of apple spurs. However, the positive effect on return bloom may be minimal in cultivars that have a strong natural tendency toward biennial bearing, or when bloom or initial fruit set are heavy in the treatment year (McArtney et al., 2007). This suggests that early reductions in crop load are a requisite prior to seed development and that high activity of GAs inhibit flower initiation (Chan and Cain, 1967). Indeed, others (Schmidt et al 2009; McArtney et al., 2007) concluded that crop load is a predominant factor influencing flower initiation and that it overrides the effect of summer exogenous ETH or NAA applications.

Concentration, application timing, number of repeat applications of plant growth regulators (PGRs), as well as cultivar propensity to BB, amount of bloom and initial fruit set have been attributed to the effectiveness of PGR sprays at enhancing return bloom. Aligning PGR application with the flower initiation period is likely one of the primary factors that will influence this outcome. Previous studies indicate that flower initiation in apple occurs during the first two-thirds of the growing season (~0 and 100 DAFB) (Buban and Faust, 1982; Foster et al., 2003) and therefore in most studies, exogenous NAA and EH sprays have been applied within this timeline (e.g. Bukovac et al., 2006; McArtney et al, 2001; Schmidt et al., 2009). The most plausible reason that ETH and NAA did not

stimulate flower initiation of 'Honeycrisp' trees in the present study is that flower initiation of this cultivar occurs very early and prior to the first PBR application. This notion is supported by observations in Geneva, NY that flower initiation of 'Honeycrisp' is completed within 30 DAFB (P. Francescatto, personal communication); however, further research is warranted to confirm this conjecture.

In the current study, NAA, ETH, and CaCl_2 all influenced fruit maturity and quality at harvest to varying degrees, and the effect varied among years. In 2014 fruit were harvested late (based on the high starch index values) in an attempt gain acceptable red colour for commercial markets. This likely led to a lower ability to discriminate NAA and ETG treatment effects on fruit quality measurements. The influence of late season applications of ETH and NAA on fruit quality has been widely reported in the literature. In many studies in which NAA was used to reduce PFD of several different apple cultivars, applications of NAA within four weeks of harvest increased fruit maturity, leading to reduced fruit firmness at harvest as well as retention of firmness following harvest (Arseneault and Cline, 2016; Schupp and Greene, 2004; Yuan and Li, 2008; Yuan and Carbaugh, 2007). Fruit treated with NAA in the present study improved fruit firmness compared with untreated fruit in two of three years. Several factors may explain these inconsistencies in the fruit firmness response between years and studies, including fruit size, number and size of cells in the fruit, level of maturity when fruit were harvested, and enzyme activity (Link, 2000). Moreover, the flesh of

'Honeycrisp' fruit has higher firmness retention than other cultivars, likely due to low enzyme activity (Harb et al. 2012).

Overall, six sprays of ETH decreased fruit firmness, increased the percent of the fruit surface red blush, and decreased fruit titratable acidity, indicating advanced fruit maturity. Three sprays of ETH, completed by mid-July, did not affect fruit quality, and effects were comparable to untreated fruit. Late-season pre-harvest foliar application of ETH has been used commercially to advance and improve fruit colouring for cultivars such as 'McIntosh,' but the quality of fruit treated with pre-harvest ETH is often compromised, making them unsuitable for long-term storage (Miller, 1975; Smith et al., 1985). Based on the present results, if flower bud initiation was found to be improved with earlier and fewer sprays of ETH in future studies, the effect of ETHC on fruit quality of 'Honeycrisp' at harvest would likely be minimal based on the present study.

NAA had less influence on fruit quality at harvest than did ETH, and in some instances, improved fruit quality and decreased PFD. NAA would therefore likely be a better candidate for repeat early season low-dose applications to enhance return bloom, should it be found to improve flower bud initiation on 'Honeycrisp' or other BB cultivars in future studies.

Since ACC significantly reduced crop density and total yield per tree (Table 43) in 2014, we were unable to determine the direct effect of ACC on fruit quality, PFD, or return bloom. Studies investigating ACC as a fruitlet apple thinner (e.g. McArtney and Obermiller, 2012) found that applications of 400 mg/L ACC—as late as 27 mm in fruit diameter—caused fruit abscission, resulting in a desired reduction in crop load. In the present experiment, 150 mg L⁻¹ ACC was used to avoid fruit thinning, and applications were made beginning 27 June, when fruit size was greater than 27 mm. It is therefore difficult to ascertain how these rates and timings caused a reduction in crop load based on previous studies. Nevertheless, ACC was not found to have the florigenic properties necessary to stimulate return bloom the following year. In future studies, it would be worth to determining conclusively whether ACC can stimulate flower initiation of BB cultivars in the ‘on’ years by using earlier applications (between full bloom and 40 DAFB) as well as lower concentrations of ACC.

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Table 1. Full bloom and application dates of foliar sprays of NAA, ethephon, calcium chloride and ACC over three years including maximum air temperatures during the day and 48hr following application.

Bloom and spray number	2009					2013				2014			
	Max. air temp (°c)				ETH, NAA, CaCl ₂ application Dates	Max. air temp (°c)			Max. air temp (°c)				
	ETH, NAA, CaCl ₂ application Dates	DAFB	on day of spraying	within 48 hrs after spraying		on day of spraying	within 48 hrs after spraying	ETH, NAA, CaCl ₂ , ACC application Dates ^a	DAFB	on day of spraying	within 48 hrs after spraying		
Bloom	10-May				12-May				21-May				
1	26-Jun	47	30.6	28.2	21-Jun	40	24.9	29.6	20-Jun	30	22.8	26.0	
2	07-Jul	58	24.7	22.9	2-Jul	51	23.1	28.7	27-Jun	27	25.3	29.8	
3	15-Jul	66	23.6	26.7	12-Jul	61	30.5	33.4	10-Jul	50	22.6	27.3	
4	27-Jul	78	25.2	27.9	24-Jul	73	22.5	21.0	21-Jul	61	26.2	20.3	
5	13-Aug	95	26.3	28.5	1-Aug	81	18.8	21.7	31-Jul	71	19.5	21.1	
6	03-Sep	116	23.2	25.4	20-Aug	100	19.2	24.5	15-Aug	86	26.0	29.9	

^a ACC was only applied 2014 on the five following dates: 27-Jun, 10-July, 21-Jul, 31-July, 15-Aug

Table 2. Effect of NAA and Ethrel sprays with and without calcium chloride on fruit yield and return bloom of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2009.

Treatment	TCSA ^a fall 2009	Yield (kg tree ⁻¹)	Total number fruit per tree	Mean fruit weight (g)	Crop density (no/TCSA) ^b	Return bloom spring 2010 (0- 5) ^c
Unsprayed control	32.2	19.4	73.5	267	2.3	3.6
3 sprays of Ethrel	32.7	13.3	52.8	255	1.7	4.0
3 sprays of Ethrel + CaCl ₂	30.8	18.3	71.0	250	2.2	4.3
3 sprays of NAA	30.9	18.8	80.3	225	2.5	3.6
3 sprays of NAA + CaCl ₂	35.7	19.6	71.3	259	1.9	3.8
6 sprays of Ethrel	36.0	24.9	92.7	265	2.6	3.2
6 sprays of Ethrel + CaCl ₂	31.3	16.3	68.6	233	2.1	3.8
6 sprays of NAA	25.5	11.9	50.0	260	1.9	3.7
6 sprays of NAA + CaCl ₂	32.4	12.4	55.4	220	1.7	4.3
<i>P</i> value	0.2430	0.2427	0.3652	0.1740	0.4241	0.1729
Contrasts ^d						
Effect of Ca	NS	NS	NS	NS	NS	*
Effect of Ethrel	NS	NS	NS	NS	NS	NS
Effect of NAA	NS	NS	NS	NS	NS	NS
Effect of 3 vs 6 sprays Ethrel	NS	NS	NS	NS	NS	*
Effect of 3 vs 6 sprays NAA	NS	*	NS	NS	NS	NS

^a Trunk cross-sectional area.

^c Determined by dividing the total number of fruit harvested in fall 2009 with the TCSA measured in fall 2009.

^c Whole tree bloom rating (0 = none, 3 = med; 5 = high).

^s NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$ respectively.

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Table 3. Effect of NAA and Ethrel sprays with and without calcium chloride on fruit yield and return bloom of 'Honeycrisp' apples.
University of Guelph, Simcoe, Ontario, 2013.

Treatment	TCSA ^a fall 2013 (cm ²)	Total fruit yield (kg/tree)	Marketable fruit yield (kg/tree)	Percent marketable yield (by weight) (%)	Mean weight of marketable fruit (g)	Crop density (no/TCSA) ^b	Pre- harvest dropped fruit (% of total fruit by number)	Return bloom spring 2014 (0-3) ^c
Untreated control	51.6	28.0	18.4	75.3 ab	267	2.04	29.3 abc	2.9 a
3 sprays of Ethrel	56.2	29.8	17.7	64.4 abc	280	2.03	33.0 ab	2.7 a
3 sprays of Ethrel + CaCl ₂	56.6	25.8	18.9	77.0 ab	283	1.66	41.5 a	2.8 a
3 sprays of NAA	64.9	28.9	15.3	56.2 c	275	1.80	28.7 abc	2.6 a
3 sprays of NAA + CaCl ₂	69.7	34.5	18.8	55.3 c	268	2.02	27.7 abc	2.4 a
6 sprays of Ethrel	59.8	25.6	17.3	68.7 abc	271	1.64	39.8 a	3.0 a
6 sprays of Ethrel + CaCl ₂	70.0	30.7	23.5	77.7 a	278	1.71	38.4 a	2.8 a
6 sprays of NAA	62.4	30.4	16.7	58.4 bc	269	2.04	16.4 c	2.5 a
6 sprays of NAA + CaCl ₂	63.4	29.3	15.4	55.6 c	276	1.90	21.7 bc	2.4 a
<i>P</i> value	0.3036	0.6899	0.0974	<0.0001	0.8039	0.7312	<0.0001	0.0206
Contrasts ^d								
Effect of Ca	NS	NS	NS	NS	NS	NS	NS	NS
Effect of Ethrel	NS	NS	NS	NS	NS	NS	*	NS
Effect of NAA	*	NS	NS	***	NS	NS	NS	**
Effect of 3 vs 6 sprays Ethrel	NS	NS	NS	NS	NS	NS	NS	NS
Effect of 3 vs 6 sprays NAA	NS	NS	NS	NS	NS	NS	**	NS

^a Trunk cross-sectional area.
^b Determined by dividing the total number of fruit harvested in fall 2013 with the TCSA measured in fall 2013.
^c Whole tree bloom rating (0 = none, 1 = low, 2 = med; 3 = high).

^d NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively. Mean values followed by the same letter are not significantly different according to Tukey's HSD test at $P = 0.05$.

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Table 4. Effect of NAA and Ethrel sprays with and without calcium chloride on fruit yield and return bloom of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2014.

Treatments	TCSA ^a fall 2014 (cm ²)	Total fruit yield (kg/tree) ^b	Marketable fruit yield (kg/tree)	Percent marketable yield (%)	Mean weight of marketable fruit (g)	Crop density (no/TCSA) ^c	Pre- harvest dropped fruit (% of total fruit/tree)	Return bloom spring 2015 (0-3) ^d
Untreated control	54.8	49.0 abc	20.3 ab	38.3 a	246 ab	4.1 a	12.5 ab	2.3 ab
3 sprays of Ethrel	67.6	53.1 ab	20.0 ab	37.1 a	271 ab	3.2 ab	12.7 ab	2.0 ab
3 sprays of Ethrel + CaCl ₂	69.9	49.6 abc	19.0 ab	37.5 a	270 ab	3.2 ab	14.9 a	2.4 ab
3 sprays of NAA	59.9	52.8 abc	20.0 ab	36.4 a	242 ab	4.1 a	8.4 bcd	2.1 ab
3 sprays of NAA + CaCl ₂	65.6	55.8 a	25.3 a	43.7 a	242 ab	4.1 a	10.6 abcd	2.2 ab
6 sprays of Ethrel	70.6	51.3 abc	26.9 a	50.4 a	247 ab	3.4 ab	11.2 abcd	2.3 ab
6 sprays of Ethrel + CaCl ₂	73.0	36.3 bcd	22.7 ab	48.6 a	258 ab	2.6 abc	12.4 abc	2.2 ab
6 sprays of NAA	65.1	56.4 a	22.1 ab	34.1 a	238 ab	4.4 a	6.0 d	1.7 b
6 sprays of NAA + CaCl ₂	73.7	51.1 abc	22.5 ab	42.7 a	232 b	3.7 ab	6.9 cd	2.4 ab
2 sprays of ACC	79.0	34.1 cd	17.5 ab	47.4 a	280 a	2.0 bc	6.8 cd	2.6 a
5 sprays of ACC	84.8	25.9 d	12.3 b	42.5 a	286 a	1.1 c	8.0 bcd	2.4 ab
<i>P</i> value	0.1090	<0.0001	0.0171	0.0193	0.0008	<0.0001	<0.0001	0.0187
Contrasts ^e								
Effect of calcium	NS	NS	NS	NS	NS	NS	NS	*
Effect of Ethrel	*	NS	NS	NS	NS	*	NS	NS
Effect of NAA	NS	NS	NS	NS	NS	NS	**	NS
Effect of ACC	***	***	NS	NS	**	***	***	NS
Effect of 3 vs 6 sprays Ethrel	NS	NS	*	***	NS	NS	NS	NS
Effect of 3 vs 6 sprays NAA	NS	NS	NS	NS	NS	NS	*	NS
Effect of 3 vs 6 sprays ACC	NS	NS	NS	NS	NS	NS	NS	NS

- ^a Trunk cross-sectional area.
- ^b Mean values followed by the same letter are not significantly different according to Tukey's HSD test at $P = 0.05$.
- ^c Determined by dividing the total number of fruit harvested in fall 2014 with the TCSA measured in fall 2014.
- ^d Whole tree bloom rating (0 = none, 1 = low, 2 = med; 3 = high).
- ^e NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

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Table 5. Effect of NAA and Ethrel sprays with and without calcium chloride on the fruit quality of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2009.

Treatment	Red blush (%) ^b		Starch Cornell Index		Soluble solids °Brix	Fruit firmness (N)	
Unsprayed Control	85.9	ab	6.4	c	13.4	62.8	ab
3 sprays of Ethrel	88.6	a	6.4	c	13.6	64.2	a
3 sprays of Ethrel + CaCl ₂	80.6	ab	6.8	abc	13.2	61.4	abc
3 sprays of NAA	87.0	ab	6.9	abc	12.3	60.4	bc
3 sprays of NAA + CaCl ₂	82.8	ab	7.3	a	12.9	60.0	bc
6 sprays of Ethrel	82.1	ab	7.3	a	13.5	60.2	bc
6 sprays of Ethrel + CaCl ₂	84.1	ab	7.4	a	13.2	59.8	c
6 sprays of NAA	86.1	ab	6.6	bc	13.7	61.3	abc
6 sprays of NAA + CaCl ₂	78.8	b	7.2	ab	12.1	60.6	bc
<i>P</i> value	0.0110		<0.0001		0.2151	<0.0001	
Contrasts ^b							
Effect of calcium	**		***		NS	*	
Effect of Ethrel	NS		***		NS	NS	
Effect of NAA	NS		***		NS	**	
Effect of 3 vs 6 sprays Ethrel	NS		***		NS	***	
Effect of 3 vs 6 sprays NAA	NS		NS		NS	NS	

^a Mean values followed by the same letter are not significantly different according to Tukey's HSD test at *P* = 0.05.

^b NS, *, **, ***, indicates not significant, and significant differences at *P* = 0.05, *P* = 0.01, and *P* = 0.001 respectively.

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Table 6. Effect of NAA and Ethrel sprays with and without calcium chloride on the fruit quality of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2013.

Treatment	Red blush (%) ^a	Starch index (1-8)	Soluble solids (°BRIX)	Titrateable acidity (mg malic acid/100 ml)	Rate of ethylene evolution at harvest (nL ethylene/g fruit/hr)	Fruit firmness at harvest (N)	Post-harvest fruit firmness (N)
Untreated Control	49.0 abc	5.9 bc	12.6 bcd	60.7 abc	13.6	61.9 ab	66.7 bc
3 sprays of Ethrel	45.2 bcd	6.1 bc	13.0 abcd	57.8 abc	9.7	60.2 bcd	65.9 cd
3 sprays of Ethrel + CaCl ₂	47.5 abcd	7.0 ab	14.0 a	61.6 ab	11.0	61.7 abc	63.9 d
3 sprays of NAA	38.2 cd	4.4 de	12.6 bcd	67.6 a	13.7	63.8 a	69.1 ab
3 sprays of NAA + CaCl ₂	42.8 bcd	5.0 cd	12.1 cd	60.2 abc	12.1	63.0 a	68.4 ab
6 sprays of Ethrel	56.7 ab	7.9 a	13.4 abc	52.3 bc	12.4	58.7 d	57.5 e
6 sprays of Ethrel + CaCl ₂	62.2 a	8.0 a	13.7 ab	50.7 c	12.5	59.3 cd	57.3 e
6 sprays of NAA	33.5 d	3.3 e	12.0 d	63.6 a	15.1	64.2 a	69.4 a
6 sprays of NAA + CaCl ₂	30.7 d	5.3 cd	12.3 cd	61.9 ab	14.7	64.0 a	69.5 a
<i>P</i> value	<0.0001	<0.0001	<0.0001	0.0001	0.0541	<0.0001	<0.0001
Contrasts ^b							
Effect of Ca	NS	***	NS	NS	NS	NS	NS
Effect of Ethrel	NS	***	**	NS	NS	**	***
Effect of NAA	**	***	NS	NS	NS	**	***
Effect of 3 vs 6 sprays Ethrel	***	***	NS	***	NS	***	***
Effect of 3 vs 6 sprays NAA	*	NS	NS	NS	NS	NS	NS

^a Mean values followed by the same letter are not significantly different according to Tukey's HSD test at *P* = 0.05.

^b NS, *, **, ***, indicates not significant, and significant differences at *P* = 0.05, *P* = 0.01, and *P* = 0.001, respectively.

Table 7. Effect of NAA and Ethrel sprays with and without calcium chloride on the fruit quality of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2014.

Treatment	Red blush (%) ^a		Starch index (1-8)	Soluble solids (°BRIX)		Titratable acidity (mg malic acid/100 ml)		Rate of ethylene evolution at harvest (nL ethylene/g fruit/hr)	Fruit firmness at harvest (N) ^y		Post-harvest fruit firmness (N)	
Untreated control	80.1	abcd	8.0	12.2	ab	39.5	ab	13.7	63.2	a	62.3	bc
3 sprays of Ethrel	78.2	abcd	7.9	12.4	ab	38.3	ab	14.7	63.8	a	61.3	c
3 sprays of Ethrel + CaCl ₂	79.5	abcd	8.0	12.7	ab	38.1	abc	16.8	64.3	a	62.3	bc
3 sprays of NAA	70.3	de	7.9	11.8	ab	41.3	ab	10.4	66.1	a	65.4	a
3 sprays of NAA + CaCl ₂	72.8	cd	8.0	12.3	ab	37.8	abc	17.0	63.6	a	63.5	abc
6 sprays of Ethrel	83.5	ab	8.0	12.5	ab	28.9	cd	20.4	59.6	b	54.8	d
6 sprays of Ethrel + CaCl ₂	83.2	abc	8.0	11.9	ab	25.6	d	16.8	59.3	b	55.0	d
6 sprays of NAA	60.6	e	7.9	11.6	b	39.8	ab	14.4	66.1	a	65.7	a
6 sprays of NAA + CaCl ₂	73.9	bcd	7.9	11.9	ab	35.9	bc	19.2	63.8	a	64.9	ab
2 sprays of ACC	83.7	ab	7.9	13.3	a	46.2	a	13.6	64.3	a	62.3	bc
5 sprays of ACC	87.0	a	8.0	13.1	ab	40.2	ab	16.8	59.4	b	53.2	d
<i>P</i> value	<0.0001		0.1952	0.0320		<0.0001		0.2510	<0.0001		<0.0001	
Contrasts ^b												
Effect of Ca	**		NS	NS		NS		NS	*		NS	
Effect of Ethrel	NS		NS	NS		**		NS	NS		***	
Effect of NAA	***		NS	NS		NS		NS	*		***	
Effect of ACC	NS		NS	*		NS		NS	NS		***	
Effect of 3 vs 6 sprays Ethrel	*		NS	NS		***		NS	***		***	
Effect of 3 vs 6 sprays NAA	NS		NS	NS		NS		NS	NS		NS	
Effect of 3 vs 6 sprays ACC	NS		NS	NS		*		NS	***		***	

^a Mean values followed by the same letter are not significantly different according to Tukey's HSD test at $P = 0.05$.

^b NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

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Table 8. Effect of NAA and Ethrel sprays with and without calcium chloride on the fruit colour of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2013.

Treatment	Blush colour ^{a,b}						Ground colour					
	L*		C*		h°		L*		C*		h°	
Untreated Control	46.28	c	38.16	abc	35.62	c	73.67	42.23	ab	107.35	bc	
3 sprays of Ethrel	48.59	abc	36.56	bcd	44.00	bc	75.13	40.76	ab	106.86	bcd	
3 sprays of Ethrel + CaCl ₂	47.36	bc	39.34	ab	37.75	c	74.82	41.51	ab	105.77	cd	
3 sprays of NAA	48.55	abc	35.52	cde	42.33	bc	74.72	41.43	ab	108.42	abc	
3 sprays of NAA + CaCl ₂	49.35	abc	34.73	de	42.69	bc	74.06	42.55	a	109.50	ab	
6 sprays of Ethrel	48.42	abc	40.06	ab	40.18	bc	74.51	40.33	ab	103.34	d	
6 sprays of Ethrel + CaCl ₂	45.81	c	41.07	a	33.28	c	75.69	39.80	b	103.95	d	
6 sprays of NAA	52.34	a	32.37	e	56.82	a	74.27	41.77	ab	111.26	a	
6 sprays of NAA + CaCl ₂	51.27	ab	34.27	de	52.03	ab	74.53	41.81	ab	109.98	ab	
<i>P</i> value	<0.0001		<0.0001		<0.0001		0.1259		0.0157		<0.0001	
Contrasts ^c												
Effect of Ca	NS		*		*		NS		NS		NS	
Effect of Ethrel	NS		NS		NS		*		*		**	
Effect of NAA	***		***		***		NS		NS		**	
Effect of 3 vs 6 sprays Ethrel	NS		**		NS		NS		NS		***	
Effect of 3 vs 6 sprays NAA	**		*		***		NS		NS		*	

^a Means of 10 fruit per experimental unit using a Konica-Minolta Chroma Meter CR-400 measuring in CIELAB. L* = lightness (0 = black, 100 = white), C* = chroma, h° = hue angle (0° = red-purple, 90° = yellow, 180° = blueish-green, 270° = blue).

^b Mean values followed by the same letter are not significantly different according to Tukey's HSD test at *P* = 0.05.

^z NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$ respectively.

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Table 9. Effect of NAA and Ethrel sprays with and without calcium chloride on the fruit colour of 'Honeycrisp' apples. University of Guelph, Simcoe, Ontario, 2014.

Treatment	Blush colour ^{a,b}						Ground colour					
	L*		C*		h°		L*		C*		h°	
Untreated control	40.84	b	42.32	bcde	26.68	b	74.87	a	38.99	ab	105.95	ab
3 sprays of Ethrel	42.35	ab	42.47	bcd	28.56	b	74.93	a	39.47	ab	104.76	abc
3 sprays of Ethrel + CaCl ₂	43.17	ab	43.17	abc	28.80	b	74.14	a	40.67	a	104.14	bcd
3 sprays of NAA	41.71	b	40.02	e	29.48	ab	74.27	a	39.82	ab	107.72	a
3 sprays of NAA + CaCl ₂	42.22	ab	42.47	bcd	27.70	b	74.87	a	40.92	a	106.38	ab
6 sprays of Ethrel	42.22	ab	44.16	abc	27.29	b	75.74	a	37.95	b	100.95	de
6 sprays of Ethrel + CaCl ₂	42.22	ab	43.95	abc	27.93	b	74.59	a	38.68	ab	102.01	cde
6 sprays of NAA	44.46	a	40.48	de	33.12	a	73.99	a	40.85	a	107.25	ab
6 sprays of NAA + CaCl ₂	42.73	ab	41.92	cde	29.01	b	74.16	a	40.28	a	106.26	ab
2 sprays of ACC	41.19	b	44.99	a	27.37	b	73.47	a	40.63	a	100.59	e
5 sprays of ACC	42.07	ab	44.80	ab	27.82	b	75.96	a	40.61	a	96.20	f
<i>P</i> value	0.0015		<0.0001		<0.0001		0.0366		<0.0001		<0.0001	
Contrasts ^c												
Effect of Ca	NS		**		*		NS		NS		NS	
Effect of Ethrel	**		NS		NS		NS		NS		***	
Effect of NAA	**		NS		**		NS		**		NS	
Effect of ACC	NS		***		NS		NS		*		***	
Effect of 3 vs 6 sprays Ethrel	NS		*		NS		NS		***		***	
Effect of 3 vs 6 sprays NAA	**		NS		**		NS		NS		NS	
Effect of 3 vs 6 sprays ACC	NS		NS		NS		**		NS		***	

^a Means of 10 fruit per experimental unit using a Konica-Minolta Chroma Meter CR-400 measuring in CIELAB. L* = lightness (0 = black, 100 = white), C* = chroma, h° = hue angle (0° = red-purple, 90° = yellow, 180° = blueish-green, 270° = blue).

^b Mean values followed by the same letter are not significantly different according to Tukey's HSD test at $P = 0.05$.

^c NS, *, **, ***, indicates not significant, and significant differences at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

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