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Thinning Response of Gala and Honeycrisp apple trees to lime sulphur and ATS blossom thinners in combination with carbaryl as a fruitlet thinner

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Abstract

Early crop load management of apple trees (*Malus domestica* Borkh.) is important to enhance fruit quality and reduce biennial bearing. Orchard experiments were conducted from 2020-23 to evaluate the thinning efficacy of blossom sprays of 2.5% lime sulphur (LS) combined with 2% mineral oil, and 2% ammonium thiosulphate (ATS), each applied alone or in combination with post-bloom fruitlet thinning with 1500 mg·L⁻¹ carbaryl on Gala and Honeycrisp trees. Blossom applications were timed using the pollen tube growth model. Treatments were compared with untreated control trees and hand thinned controls. Averaged over the four years and two cultivars, ATS and LS reduced fruit set by 9% and 29%, and crop load by 13% and 21%, respectively, relative to untreated controls. The carbaryl fruitlet treatment provided greater reductions in fruit set and crop load, but the integration of blossom and fruitlet thinner provided superior performance. In one year when natural crop loads were high, both blossom thinners significantly enhanced return bloom of Honeycrisp. Overall, blossom thinners provided only modest and inconsistent reductions in fruit set, but their use in sequential thinning programs may benefit biennial-prone cultivars by enhancing return bloom under heavy fruiting conditions. The benefits of early crop load reduction using LS and ATS blossom thinners need to be balanced with product costs, thinning efficacy, risk of natural

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thinning by frost, leaf phytotoxicity, and potential fruit russetting. Future research should focus on developing cost-effective blossom thinners with the aim of providing more consistent early reductions in crop load.

Keywords: ammonium thiosulphate, mineral oil, precision thinning, crop load management, chemical thinning; *Malus domestica* (Borhk)

Introduction

Early adjustment of apple (*Malus domestica* Borhk) crop load at bloom is a strategy used by producers for several purposes. It partially removes developing fruit to reach a target crop load, reduces the requirement for hand-thinning, and increases flower initiation and return flowering in the following growing season. However, managing the crop load of apples remains a significant challenge to producers, in part because of the unpredictability of fruit set and fruitlet abscission, and tree response to blossom and fruitlet thinning compounds. For this reason, there is increasing interest amongst growers to apply thinning compounds multiple times during the spring following judicious dormant pruning, first by chemical blossom thinning, followed by chemical fruitlet thinning, and finally, if necessary, touch-up hand thinning. Pomologists have referred to this process as “precision crop load management” (Robinson et al. 2013). The primary goal is to thin early (and often if necessary), sequentially reducing crop load with each application to achieve a target crop load. With a multi-application thinning program, there is a risk of overthinning; however, growers frequently under thin, resulting in the onerous task of hand thinning after natural fruit abscission (“June drop”).

One advantage of early thinning at bloom is increased carbohydrate supply to developing inflorescences and fruitlets that persist until harvest (Dash et al. 2013; Lakso et al. 1996). Apart from selective dormant pruning of flower buds prior to bloom (Breen et al. 2016; Webster 2002), thinning at bloom is the first opportunity in the growing season to manage crop load. Blossom thinners have been classified as either caustic or hormonal, and in Canada, only caustic thinners are available for thinning apples. Caustic thinners impede fertilization of the ovary by disrupting germination and growth of pollen; therefore, timing applications of blossom thinners is critical (Kon and Schupp

2018). This also led to the development of the pollen growth tube blossom thinning model (PTGM; Yoder et al. 2009, 2013; Peck et al. 2016; Peck and Olmstead 2018). The PTGM model aims to limit fruit set by applying blossom thinners after a pre-determined number of flowers have been fertilized. Using cultivar specific style length (that varies by year and orchard), from 50 measured flowers, pollen growth rate, and air temperature, the PTGM predicts the time required for the flowers to be fertilized once pollen reaches the stigma. In addition, the predicted time to apply blossom thinners is based on the desired number of flowers (ideally king flowers) to be fertilized per tree, which is approximately 25% higher than the target number of fruit per tree, and prior to a significant number of lateral flowers opening. The PTGM is then 'initiated' and predicts the time required for pollen to reach the ovary. At this stage, the first blossom thinners are applied, and the PTGM is initiated again to time a second application. For a comprehensive review on early crop load management of apple, see Kon and Schupp (2018). The authors have examined the advantages and disadvantages of early thinning, evaluated various blossom-thinner chemicals and mechanical thinning, and discussed post-bloom thinners extensively.

Lime sulfur (LS; calcium polysulfide) is reportedly one of the most consistent caustic blossom thinners available (Schmidt et al. 2011). It is often combined with fish or mineral oil to increase thinning efficacy (Schupp et al. 2005). LS has a longer period of activity compared to other caustic bloom thinners (Schmidt and Elfving 2007), in part because it has several modes of action, including inhibition of pollen tube growth (Embree and Foster 1999; Kon et al. 2018; Yoder et al. 2009) and temporary impairment of photosynthesis (McArtney et al. 2006).

Ammonium thiosulfate (ATS), a nitrogenous fertilizer, is another caustic thinner which has been used as a blossom thinner in the apple industry for over two decades (Byers 2003). However, thinning results with ATS have been more inconsistent (Hampson and Bedford 2011; Miller and Tworkoski 2010). ATS damages flower parts (especially stigmas and styles) when applied during bloom, preventing successful fertilization and fruit set. The extent of thinning depends on spray timing, concentration, temperature,

humidity, and coverage (Byers 1997; Greene 2002). ATS is usually applied at 80–90% bloom, sometimes in multiple sprays, but later applications can cause fruit russetting and phytotoxicity to spur leaves. Several other types of bloom thinners have been used, including corn oil emulsions for apple, peach, and sweet cherries (Ju et al. 2001; Kon and Schupp 2018) and essential oils for peach and apple (Miller and Tworkoski 2010). However, these have not been widely commercially adopted.

In Eastern Canada and the United States, post-bloom fruitlet thinners (carbaryl (CB), naphthaleneacetic acid, 6-benzyladenine (6-BA), 1-aminocyclopropane-1-carboxylic acid and the soon to be registered metamitron) are more common than blossom thinners. This is in part because of their wider window of efficacy, which ranges from ~5 mm fruitlet diameter (at petal fall) to ~20 mm fruitlet diameter. Moreover, Southern Ontario has a humid continental climate, primarily classified as Köppen Dfa or Dfb, with variable spring weather, making flowers susceptible to spring frost. Despite this, to reduce reliance on hand thinning and minimize biennial bearing, growers are seeking options to incorporate earlier thinning in their thinning programs.

Limited information is available regarding the use and efficacy of caustic blossom thinners in the apple growing regions of Southern Ontario. The objective of this trial was to evaluate the efficacy of the blossom thinning products i) LS tank mixed with mineral oil and ii) ATS on fruit set, crop load, return bloom, and other yield parameters. Both treatments were applied with and without CB as a fruitlet thinner. The PTGM was used to time applications of LS and ATS.

Materials and Methods

Methods common to all experiments

Experiments were conducted at the University of Guelph, Ontario Crops Research Centre-Simcoe, Simcoe, Ontario (42°51'40" N, 80°16'8" W). Trees were supplied with trickle irrigation via 2 L h⁻¹ pressure-compensating emitters spaced 45 cm apart and watered daily during the growing season with an equivalent of ~2.5 cm of water weekly (adjusted for natural rainfall) on a schedule of four irrigation run-times per day every 6 h

(20 min per event). Standard cultural and pest management practices for Ontario were followed (Ontario Ministry of Agriculture, Food and Rural Affairs 2018). Granular fertilizer (N-P-K) was applied in the spring each season prior to bud-break. Weeds were controlled within a 1-m wide strip on each side of the tree row using a spring application of 0.075 kg/ha indaziflam and 1% (v/v) glyphosate applications made mid-June and July. A permanent sod culture was established at the time of planting in the row middle using a mixture of 40% perennial rye and 60% red fescue (Vineland Growers, Vineland, Ontario). Daily maximum and minimum air temperatures, precipitation and solar radiation were recorded by a weather station located within 500 m of the research orchards. All treatment trees were selected for adequate and uniform bloom.

Experiment 1: Brookfield Gala

This study, conducted in 2020 and 2021, used a block of Brookfield Gala on M.9 T337 rootstock. Trees were planted in 2017 at a spacing of 0.90 m x 3.5 m (3175 trees ha⁻¹) and trained to a spindle solid hedgerow orchard system. The orchard soil consisted of a Wilsonville sandy loam (Brunisolic Grey Brown Luvisol) (Presant and Acton 1984) with rapid drainage and soil textures consisting of mainly fine sandy loam over loamy sand and gravelly sand to a depth of 60 cm (Hohner and Presant 1989).

There were seven treatments consisting of: i) untreated control; ii) hand-thinned control; iii) 75 mg L⁻¹ 6-BA (Maxcel, Valent Bioscience, Guelph, Ontario) combined with 1500 mg L⁻¹ CB (Sevin XLR; Tessenderlo Kerley Inc., Phoenix, Arizona) applied at 12 mm king fruitlet diameter; iv) 2% ATS; 12-0-0-26S, Norwich Fertilizer, Norwich, Ontario) applied at bloom; v) 2% ATS applied at bloom followed by 75 mg L⁻¹ 6-BA combined with 1500 mg L⁻¹ CB applied at 12 mm king fruitlet diameter; vi) 2.5% LS (Oligo-S, Axter Agrosience, Mont-St-Hilaire, Quebec) combined with 2% (v/v) mineral oil (Purespray Green Spray Oil 13E, Intelligro, Mississauga, Ontario) applied at bloom; and vii) 2% (v/v) LS combined with mineral oil applied at bloom followed by 75 mg L⁻¹ 6-BA combined with 1500 mg L⁻¹ CB applied at 12 mm king fruitlet diameter. To enhance product uptake, and reduce surface tension, all spray treatments included 0.05% Regulaid® non-ionic spray adjuvant (2-butoxyethanol, poloxalene, monopropylene glycol, KALO, Inc., Overland

Park, USA). A randomized complete block with five replications was used as the experimental design.

Experiment 2: Honeycrisp

This study, conducted in 2022 and 2023, used a block of Honeycrisp on Bud 9 rootstock. Trees were planted in 2018 at a spacing of 1 m x 4 m (2500 trees ha⁻¹) and trained to a spindle solid hedgerow orchard system. The orchard soil consisted of a Tavistock loam (Brunisolic Grey Brown Luvisol) (Presant and Acton 1984) with imperfect drainage and soil textures consisting of mainly loam over very fine sandy loam and silty clay loam to a depth of 110 cm (Hohner and Presant 1989).

There were seven treatments consisting of: i) untreated control; ii) hand-thinned control; iii) 1500 mg L⁻¹ CB (Sevin XLR; Tessenderlo Kerley Inc., Phoenix, Arizona) applied at 12 mm king fruitlet diameter; iv) two applications of 2% ATS (12-0-0-26S Norwich Fertilizer, Norwich, Ontario) applied at bloom; v) two applications of 2% ATS applied at bloom followed by 1500 mg L⁻¹ CB applied at 12 mm king fruitlet diameter; vi) two applications of 2.5% LS (Oligo-S, Axter Agrosience, Mont-St-Hilaire, Quebec) combined with 2% (v/v) mineral oil (Purespray Green Spray Oil 13E, Intelligro, Mississauga, Ontario) applied at bloom; and vii) two applications of 2% (v/v) LS combined with mineral oil applied at bloom followed by 1500 mg L⁻¹ CB applied at 12 mm king fruitlet diameter. All spray treatments included 0.05% Regulaid® non-ionic spray adjuvant (2-butoxyethanol, poloxalene, monopropylene glycol, KALO, Inc., Overland Park, USA). A randomized complete block with five replications in 2022 and six replications in 2023 was used as the experimental design.

Method of treatment application

Treatments were applied using a commercial air blast sprayer (GB Irrorazione Diserbo, Model Laser P7, Italy) at 1379 kPa, 1217 L ha⁻¹, which equated to tree row volume pesticide dilute (Sutton and Unrath 1988). The sprayer was equipped with five nozzles per boom (side) and 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 one guard tree. Applications were made in low wind conditions, usually between

6:30-10:30 am. Municipal ground water was used as the source water for the spray mixture. The water has an average pH ranging from 7.50 to 7.98 and hardness range of 281 mg L⁻¹ to 295 mg L⁻¹ (Kristin Pressey, personal communications). The first application of blossom thinners were timed using the PTGM and were repeated 27 h (2020), 82 h (2021), 71 h (2022) and 124 h (2023) later (Table 1).

The PTGM is available on the Network for Environment and Weather Applications (NEWA) platform (NEWA 2025) in the United States but is not available in Ontario. For all experiments reported in this study, an Excel version of a PTGM for Gala and Honeycrisp was provide in 2020 by Prof. Greg Peck at Cornell University. It is our understanding that this is the model used on the NEWA Platform. As an aside, the PTGM can be accessed by subscription to RIMPRO, a commercial decision support system for the management of pests and apple and grape diseases (RIMPRO 2025; RIMPRO bv, Amsterdam, The Netherlands) however because of limited, publicly available information on the assumptions of this model, it is unclear if the NEWA PTGM is the same as the RIMPro PTGM (Trapman, 2018).

Fruitlet thinners were timed by periodically measuring the longitudinal diameter of 30-100 king and 30-100 lateral fruits using digital calipers. The dates of full bloom were 25-May 2020, 10-May 2021, 19-May 2022, and 15-May 2023. Treatment application dates for the first and second blossom thinner applications were 26- and 27-May 2020, 13- and 17-May 2021, 15- and 18-May 2022, 16- and 21-May 2023, respectively. Fruitlet thinning treatments were applied on 9-June 2020 (average king 12.9 mm, lateral 10.8 mm, n = 50), 30-May 2021 (average king 11.2 mm, lateral 9.1 mm, n = 50), 2-June 2022 (average king 12.1 mm, lateral 9.4 mm, n = 100) and 30-May 2023 (average king 12.9 mm, n = 30). The hand-thinned control trees were thinned by hand on 8-July 2020, 13-July 2021, 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Horticultural Measurements

Tree trunk circumference at 30 cm above the graft union was measured at the beginning and end of each growing season, from which trunk cross-sectional area (TCSA) was calculated. Four scaffold branches—two on the east and two on the west side of the

tree—were selected prior to bloom to determine fruit set. On 13-May 2020, 3-May 2021, 11-May 2022, and 9-May 2023, the number of flower clusters per branch were counted on each marked limb. Number of fruit set per limb were counted after June drop on 24-June 2020, 12-July 2021, 29-July 2022, and 23-June 2023. These data were averaged and used to calculate percent fruit set (number of fruit set divided by number of flowers).

Leaf phytotoxicity was assessed once in 2020 (18-June), five times in 2021 (27-May and 1-, 8-, 11-, and 16-June), four times in 2022 (2-, 9-, 15-, 23-June) and three times in 2023 (1-, 9-, 15-June). This was done by rating the incidence and severity of necrosis using a scale of 0 to 5, where 0=none, 1= very slight, 2= slight, 3= moderate, 4= high, and 5= very high.

Fruit were harvested on 14-Sept 2020, 13-Sept 2021, 20-Sept 2022, and 21-Sept 2023. During harvest, the total number and weight of fruit were recorded. Number of unmarketable fruit (undersize, poor colour, premature fruit drop) was also counted and weighed. Mean fruit size was estimated by dividing total mass of fruit by the total number of fruit in the sample. Mean size of marketable fruit was estimated by dividing the total mass of marketable fruit by the number of marketable fruit in the sample. A random sample of approximately 5 kg of marketable fruit per tree was taken from each experimental unit and placed in cold storage (~2°C) for subsequent grading in November of each year. Fruit were graded using a commercial grader with sizing (MAF Roda, Montauban, France, Model GlobalScan7) and colour sorting (MAF, Orpheus) capabilities (Norfolk Fruit Growers Association in Simcoe, Ontario) which uses cameras and sensors to detect surface colour and intensity, background colour, and the mass and size dimensions of each fruit. Individual fruit weights and colours were recorded from each sample of fruit. Fruit length and diameter (L:D) ratios were also determined by image analyses from the grading line. Fruit weight data were used to separate each fruit in the grading sample into 15 size categories expressed as an average count size, which was the number of apples needed to fill an 18 kg box (Canadian Food Inspection Agency, 2011). Individual fruit weight ranges for each category were: 1) < 91 g (count size 216), 2) 91-102 g (count size 198), 3) 103-110 g (count size 175), 4) 111-120 g (count size 163), 5) 121-130 g (count size 150), 6) 131-144 g (count size 138), 7) 145-

159 g (count size 125), 8) 160-180 g (count size 113), 9) 181-205 g (count size 100), 10) 206-225 g (count size 88), 11) 226-250 g (count size 80), 12) 251-282 g (count size 72), 13) 283-322 g (count size 64), 14) 323-376 g (count size 56), and 15) > 377 g (count size 48). Total weight of fruit per tree in each count size category was calculated by multiplying the percentage of fruit in each category by the total weight of fruit per tree (recorded at harvest).

Gross value of fruit per tree was calculated based on the weight of marketable fruit in each category and the wholesale market price of fruit in each size category (count size 72 to 216). Wholesale prices of Gala apples were obtained from a commercial packing house in Ontario which provided the following prices based on an 18 kg (40 lb) count size box of fruit (in parenthesis): \$1.16/kg (48, 56, 64), \$1.35/kg (72, 80, 88), \$1.16/kg (100, 113), \$0.73/kg (125, 138, 150), \$0.44/kg (163, 175), \$0.34/kg (198, 216).

Wholesale prices include packing and storage costs, bin rental, and marketing costs, but exclude unmarketable fruit due to poor colour or blemishes.

Return bloom was recorded in spring (when flower clusters were evident but prior to full bloom) of the year following treatment application on 28-Apr 2021, 10-May 2022, 3-May 2023, and 30-Apr 2024. Percentage of flowering spurs was determined by counting the number of spurs with and without flowers on four limbs per tree located 1.5 m to 2 m above the ground.

Statistical Analysis

Data were subjected to analysis of variance using the PROC GLIMMIX procedure of SAS (SAS 9.4 SAS Institute, Cary, N.C.). Mean fruit weight was adjusted by using crop load as a co-variate. Mean separation using Tukey's HSD was used to separate treatment means ($P=0.05$). A Shapiro-Wilk test was used to test normality of the residuals. Scatterplots of studentized residuals were visually observed to test the assumption that errors were not heterogeneous. In cases where there were large deviations from the assumptions, data were transformed using log- or square root-transformation prior to analysis. All graphs were created using SigmaPlot version 11.0 (Systat Software, Inc., Germany).

Results

Experiment 1: Brookfield Gala/M.9 T337

Fruit Set

Fruit set counts were recorded prior to hand-thinning. No statistically significant differences between the untreated and hand-thinned controls in mean fruit set or percent of spurs with various numbers of fruit set were observed in either year (Figure 1). There was a significant treatment effect on mean fruit set in 2020 ($P=0.0008$) and 2021 ($P<0.0001$). In 2020, blossom thinning with LS followed by fruitlet thinning significantly reduced mean fruit set compared to the control treatments and ATS blossom thinning treatment based on the mean separation. In 2021, the control and LS blossom thinning only treatments resulted in the highest mean fruit set, while the blossom thinning followed by fruitlet thinning treatments had the lowest fruit set. The grower standard CB tank mixed with 6-BA fruitlet thinning treatment resulted in a moderate amount of thinning. Based on the mean separation and despite numerical differences, the ATS blossom thinning with and without fruitlet thinning and LS blossom thinning followed by fruitlet thinning treatments were statistically similar to the grower standard CB with 6-BA fruitlet thinning treatments. Contrasts indicated a significant reduction in fruit set when trees were sprayed with the grower standard CB with 6-BA fruitlet thinning treatment compared to the blossom thinning treatment alone in both 2020 ($P=0.05$) and 2021 ($P=0.01$). The combination of blossom thinning plus fruitlet thinning resulted in significantly lower fruit set compared to blossom thinning alone in 2020 ($P=0.01$) and 2021 ($P=0.001$).

There was a significant treatment effect on the percent of flowering spurs which set no (zero) fruit in 2020 ($P=0.0008$), although there were few differences among the treatments according to the mean separation (Table 2). LS blossom thinning followed by fruitlet thinning, which had the lowest mean fruit set, also had the highest percent of spurs with zero fruit set in 2020. In 2021, all chemical thinning treatments except for blossom thinning alone significantly increased the number of spurs with zero fruit compared to the untreated and hand-thinned controls. ATS and LS blossom thinning

followed by fruitlet thinning resulted in the highest percent of spurs with no fruit set. Trees treated with ATS blossom thinning alone and blossom thinning followed by fruitlet thinning had a percent zero fruit set that was similar to the grower standard CB with 6-BA treatment. Based on the orthogonal contrasts, on average, fruitlet thinning significantly increased the percent of spurs with zero fruit compared to blossom thinning in 2020 ($P=0.05$) and in 2021 ($P=0.01$). The addition of fruitlet thinning to blossom thinning significantly increased the percent of spurs with zero fruit set from an average of 78.5 to 89.8% in 2020 ($P=0.01$) and from 72.0 to 92.9% in 2021 ($P=0.001$).

Thinning treatments had a significant effect on the percent of flowering spurs which set a single fruit in 2020 ($P=0.0009$) and 2021 ($P<0.0001$). LS blossom thinning followed by fruitlet thinning significantly decreased the percent of spurs with one fruit compared to the control treatments and ATS blossom thinning alone in 2020. In 2021, all chemical thinning treatments except for blossom thinning alone significantly reduced the percent of spurs with one fruit compared to the control treatments. Blossom thinning treatments followed by fruitlet thinning resulted in the lowest percent of spurs with one fruit, but these were statistically similar to the grower standard CB with 6-BA fruitlet thinning treatment. Based on the orthogonal contrasts, blossom thinning alone had significantly more spurs with one fruit compared to fruitlet thinning alone in 2020 ($P=0.05$) and 2021 ($P=0.01$). Adding fruitlet thinning treatments to ATS and LS blossom thinning reduced the percent of spurs with one fruit from 20.7% to 10.0% on average in 2020 ($P=0.01$) and from 24.8% to 6.9% in 2021 ($P=0.001$). Thinning treatments significantly affected the percent of spurs with two fruit set in 2021 ($P=0.0142$) but not in 2020 ($P=0.5327$). The combination of blossom thinning followed by fruitlet thinning significantly reduced the percent of spurs with two fruit compared to the hand thinned control. On average, the addition of fruitlet thinning to the ATS and LS blossom thinning treatments reduced the percent of spurs with two fruit from 2.9% to 0.1% ($P=0.01$) in 2021. The percentage of spurs with three or four fruit in 2021 was not affected by the thinning treatments.

Yield

In 2020, total yield, marketable yield, total number of fruit per tree and crop load were highest from the untreated control trees, followed by the ATS blossom thinning treatment (Table 3, Fig. 2). Trees receiving LS alone, or LS and ATS followed by CB with 6-BA, or CB with 6-BA alone had the lowest total yield, marketable yield, total number of fruit per tree, and crop load. In 2021, total yield was significantly lower with the combination of blossom thinning followed by fruitlet thinning compared to the other treatments. All of the thinning treatments, except for the blossom thinning followed by fruitlet thinning treatments, were similar to the hand-thinned control and grower standard fruitlet thinning treatments. In both years of the experiment, treatments that resulted in the greatest degree of fruit thinning also produced the lowest total yield. This was apparent by the significant additive effect of fruitlet thinning to blossom thinning which, on average, significantly reduced total yield compared to blossom thinning alone in 2020 ($P=0.01$) and 2021 ($P=0.001$). The combination of blossom thinning followed by fruitlet thinning also significantly reduced marketable yield compared to the other treatments. This result is also supported by the orthogonal contrasts, which indicated a reduction in marketable yield of 5.9 kg/tree with the addition of fruitlet thinning compared to blossom thinning alone ($P=0.001$). Total number of fruit followed a similar trend as total yield, with the highest number of fruit on the untreated control trees, followed by LS blossom thinned trees and the hand-thinned control. The total number of fruit on trees treated with fruitlet thinning alone or blossom thinning alone was statistically similar to the hand-thinned control. Trees thinned with a combination of blossom thinning and fruitlet thinning produced the lowest total number of fruit. The orthogonal contrasts also indicated a significant reduction in total fruit number with the combination of blossom thinning and fruitlet thinning compared to blossom thinning alone ($P=0.001$). Mean weight of all harvested fruit was highest in treatments that resulted in the greatest degree of thinning. However, all treatments were statistically similar to the hand-thinned control and grower standard fruitlet thinning treatment, with the exception of the ATS blossom thinning followed by fruitlet thinning treatment. Fruit weights were significantly higher when trees were both blossom and fruitlet thinned compared to blossom thinned alone ($P=0.001$).

Crop load was highest for the untreated control trees (Figure 2). Blossom thinning alone resulted in similar crop load to the hand-thinned control and grower standard fruitlet thinning treatments. The addition of fruitlet thinning to blossom thinning resulted in the lowest crop load. This result was supported by the orthogonal contrasts, which indicated a reduction of 3.2 fruit/cm² TCSA with the combination of blossom and fruitlet thinning ($P=0.001$). This was apparent by the significant additive effect of fruitlet thinning to blossom thinning which, on average, significantly reduced these yield parameters ($P=0.001$).

In 2020, the gross value of fruit per hectare followed an inverse relationship with the amount of thinning. This is because the untreated control trees had suboptimal fruit set. Consequently, 95% of fruit were marketable and had an average fruit size of 182 g (Table 3). Any application of blossom or fruitlet thinner reduced crop loads even further, resulting in lower yields and crop values per tree. As a result, trees receiving any of the thinning treatments, including the hand-thinned control, had lower gross fruit value compared to the untreated control. Of the chemical thinning treatments, only the ATS blossom thinning treatment had crop values similar to the hand thinned control. The orthogonal contrasts indicated a significant increase in crop value with blossom thinning alone compared to fruitlet thinning alone or the combination of blossom thinning and fruitlet thinning ($P=0.001$).

Yield parameters in 2021 were significantly affected by the thinning treatments (Table 3). Crop value followed a similar trend to total fruit yield and total number of fruit, with treatments that resulted in a greater degree of thinning also resulting in lower economic return. All thinning treatments reduced crop values compared to the untreated control. Fruitlet thinning alone and ATS blossom thinning resulted in a similar crop values as the hand-thinned control. LS blossom thinning was also similar to the grower standard fruitlet thinning treatment. On average, crop value was similar between the blossom thinned and fruitlet thinned treatments, as indicated by the orthogonal contrasts. The additive effect of fruitlet thinning was again apparent, decreasing values by approximately 50% compared to blossom thinning treatments alone ($P=0.001$).

Fruit Size Distribution

Fruit larger than or equal to 64 mm diameter (163 count size) are considered commercially marketable. In 2020, nearly all fruit, regardless of treatment, well exceeded this minimum size (Table 4). Treatments influenced the weight of fruit in the 80- to 150-count size categories. Treatments with the greatest thinning efficacy and lowest fruit set also had the lowest number of fruit in these size categories. On average, blossom thinning followed by fruitlet thinning reduced the weight of fruit in the 88-, 100-, 113- and 125-count size categories compared to blossom thinning alone ($P \leq 0.05$).

In 2021, thinning treatments had a significant effect on the 64-, 72-, and 100- to 125-count size categories (Table 4). There was negligible fruit in the 64-count size category, and although ANOVA indicated significant treatment differences, no differences were indicated by the means separation. However, according to the orthogonal contrasts, the combination of blossom and fruitlet thinning significantly increased the amount of fruit in the 64-count size category compared to blossom thinning alone ($P = 0.0401$). The combination of blossom thinning with ATS and fruitlet thinning resulted in a significantly greater amount of fruit in the 72-count category compared to the untreated control and LS blossom thinning treatment. The contrasts also indicated a significant increase in this category when fruitlet thinning followed the blossom thinned treatments ($P = 0.01$). Although the treatment effect for the 80-count size category did not reach significance ($P = 0.0823$), the means separation indicated significantly more fruit following fruitlet thinning alone compared to the untreated control.

In 2021, orthogonal contrasts also indicated significantly more fruit in the 80-count category with fruitlet thinning alone compared to blossom thinning alone ($P = 0.05$). The combination of ATS blossom thinning followed by fruitlet thinning resulted in significantly fewer fruit in the 100-count size category compared to the untreated control or ATS blossom thinned treatments alone. However, none of the thinning treatments were significantly different from the hand-thinned control. Based on the orthogonal contrast, the addition of fruitlet thinning to the blossom thinned treatments significantly reduced the number of fruit in the 100-, 113- and 125-count size categories ($P = 0.001$, $P = 0.001$,

and $P=0.05$, respectively). The amount of fruit in the 113- and 125-count size categories was highest in the untreated control and lowest with the combination of blossom thinning and fruitlet thinning.

Leaf Phytotoxicity

Leaf curling and necrosis was observed in all treatments, including the untreated control, but severity was low, ranging from very slight to slight in 2020 (Table 5). The severity of leaf curling, however, was similar among all treatments. Leaf necrosis was more prevalent in treatments that were blossom thinned compared to the untreated control. The contrasts also indicated that blossom thinning increased the incidence of necrosis compared to fruitlet thinning ($P=0.05$). Trees blossom thinned with ATS, with or without fruitlet thinning, exhibited significantly greater severity of leaf necrosis compared to untreated trees. On average, leaf necrosis was also more severe in trees that were blossom thinned compared to trees that were fruitlet thinned ($P=0.001$).

Leaf necrosis was observed in all treatments but severity was low, ranging from slight to very slight in 2021 (Table 6). Incidence of leaf necrosis on the 27-May, 1-June and 8-June assessments was unaffected by thinning treatments. Incidence of necrosis on 11-June was significantly lower in untreated control trees compared to the ATS and LS blossom thinning treatments with or without fruitlet thinning. On 16-June, incidence of necrosis was significantly lower in the untreated control compared to all other treatments.

On 27-May and 1-June, leaf necrosis was more severe in trees that were blossom thinned with ATS compared to the grower standard fruitlet thinned, hand-thinned and untreated control treatments. Severity of necrosis was higher on the 8- and 11-June assessments for ATS blossom thinned treatments, with or without fruitlet thinning, compared to the fruitlet thinned alone, hand-thinned, and untreated control treatments. The contrasts indicated that on average, blossom thinning increased the severity of leaf necrosis compared to fruitlet thinning ($P=0.001$) for the 27-May to 11-June assessments. On 16-June, necrosis was less severe in the untreated control compared to the other treatments.

Fruit Quality

Thinning treatments had no effect on any fruit quality parameters in 2020 or 2021 (data not shown). These parameters included fruit density, fruit length-to-width ratio, percentage of fruit surface with red blush, skin blush hue, and ground colour.

Return bloom

Thinning treatments had a significant effect on the percentage of spurs with flowers in the spring of 2021 ($P=0.0095$) and 2022 ($P=0.0176$) (Table 7). The untreated control (76%) and trees treated with ATS (79.4%) in 2020 had the lowest return bloom in 2021, while trees treated with the grower standard CB with 6-BA treatment had the highest return bloom (92.3%). Orthogonal contrasts indicated that the fruitlet thinning treatments had higher return bloom than blossom thinning, and there was no difference on return bloom between blossom thinning alone and the combination of blossom thinning and fruitlet thinning. For treatments applied in 2021, return bloom was greatest on trees that received blossom thinners combined with fruitlet thinners, and was lowest for the untreated control (58.6%). Orthogonal contrasts indicated that return bloom was similar between blossom thinning alone and fruitlet thinning alone, but higher in trees with the combination of blossom thinning and fruitlet thinning compared to blossom thinning alone ($P=0.05$).

Experiment 2: Honeycrisp

Fruit Set

In 2022, there was a significant treatment effect on fruit set ($P < 0.0029$) (Figure 3). The untreated control had the highest fruit set while the LS blossom thinning treatment had the lowest fruit set, with a reduction of 58% compared to the untreated control. The ATS blossom thinning followed by CB fruitlet thinning treatment resulted in a 51% decrease in fruit set compared to the untreated control. The grower standard CB fruitlet thinning treatment resulted in only slightly reduced fruit set and was statistically similar to the hand thinned and untreated control.

Fruit set in 2023 was markedly lower than in 2022. Thinning treatments also had a significant effect on fruit set in 2023 ($P=0.0002$) (Figure 3). The ATS blossom thinning treatment resulted in the highest mean fruit set while the ATS blossom thinning followed by CB fruitlet thinning treatment had the lowest fruit set. CB fruitlet thinning alone resulted in a 33% reduction in fruit set compared to the untreated or hand thinned control although this reduction was not statistically significant based on the mean separation. The treatments that combined blossom thinning and fruitlet thinning resulted in significant reductions in fruit set of 41-46% compared to the untreated control. Application of LS, ATS or LS followed by CB fruitlet thinning resulted in similar mean fruit set to the grower standard CB fruitlet thinning treatment. Overall, ATS or LS alone did not reduce fruit set compared to the untreated control treatment.

In 2022, thinning treatments had a significant effect of the percentage of flowering spurs with zero fruit ($P=0.0119$) and two fruit ($P=0.0068$), but no effect on flowering spurs with one fruit or three or more fruit (Table 8). In 2022, the CB fruitlet thinning treatment had the lowest percentage of flowering spurs with zero fruit and the highest percentage of flowering spurs with two fruit. However, all treatments had similar percentages of flowering spurs to the untreated control for zero or more fruit per cluster.

In 2023, thinning treatments had a significant effect of the percentage of flowering spurs with zero ($P<0.0001$), one ($P=0.0003$) and two fruit ($P=0.0068$), but no effect on flowering spurs with three or more fruit (Table 8). In 2022, the ATS blossom thinning and untreated control treatments had the lowest percentage of flowering spurs with zero fruit. The ATS blossom treatment followed by CB fruitlet thinner had the lowest percentage of flowering spurs with one fruit per cluster followed by the CB fruitlet thinner alone. Orthogonal contrasts indicated that trees that received the CB fruitlet thinner treatment alone had significantly more flowering spurs with zero fruit compared to trees receiving blossom thinners alone ($P=0.001$). The combination of blossom thinning and fruitlet thinning had more flowering spurs compared to blossom thinning alone ($P=0.0001$). The same observations were made for flowering spurs that set one fruit.

Yield parameters

Application of blossom and fruitlet thinners in 2022 reduced total fruit yield by 22-41% compared to the untreated control, but results did not reach statistical significance ($P=0.0788$; Table 9). Of the other measured yield parameters, including crop load, percent marketable fruit, mean fruit weight and crop load (Figure 4), only the total number of fruit per tree was significantly affected by the thinning treatments ($P=0.0314$). Only the hand thinned control and ATS followed by CB fruitlet thinning treatment significantly reduced total number of fruit compared to the untreated control.

In 2023, total fruit yield was not significantly affected by the thinning treatments; however, treatments did affect the total number of fruit per tree ($P=0.0113$) and mean fruit weight ($P<0.0001$). Blossom thinning with ATS resulted in the greatest number of fruit while the hand-thinned control and ATS followed by CB fruitlet thinning treatments had the lowest number of fruit per tree. However, all thinning treatments had statistically similar fruit numbers to the untreated and hand-thinned control treatments. The untreated control and ATS treatments resulted in the lowest fruit weight, while the hand-thinned control treatment and trees that received the CB fruitlet treatment had the greatest fruit weights. Orthogonal contrasts indicated that application of blossom thinners alone had a greater number of fruit per tree compared to CB fruitlet thinning alone and blossom thinning followed by CB fruitlet thinning.

Fruit Size Distribution

Nearly all fruit, regardless of treatment, well exceeded the 163-count minimum size category in 2023 (Table 10; there was no data for 2022). Treatments influenced the weight of fruit in the 56-, 64-, 72-, 113-, 125-, 138- and 163-size categories. Treatments with the greatest thinning efficacy and lowest fruit set also had the lowest number of fruit in these size categories. On average, blossom thinning followed by fruitlet thinning increased the weight of fruit in the 56-, 64-, and 72-size categories compared to blossom thinning alone ($P\leq 0.05$). The combination of blossom thinning with and without fruitlet thinning resulted in significantly greater amounts of fruit in the 56-, 64-, 72-, 100-

through 150-size categories based on orthogonal contrasts. Generally, trees treated with the standard fruitlet CB grower control had more fruit in the larger size categories than trees treated with ATS and LS plus mineral oil.

Leaf Phytotoxicity

Leaf necrosis was observed in all treatments in 2022 and 2023, but severity was low, ranging from slight to very slight (data not shown). In 2022, incidence of necrosis on 15- and 23-June was significantly higher for trees treated with fruitlet sprays of CB alone. Compared with the untreated control trees, there were no measurable differences in leaf phytotoxicity following application of ATS or LS at any of the assessment dates in either year of the study.

Fruit Quality

Thinning treatments had a significant effect on fruit density ($P=0.0031$), skin percent red ($P<0.0001$), skin ground ($P<0.0001$) and hue ($P=0.0006$) colour (Table 11; 2022 data not available). Blossom thinners applied alone did not affect fruit density, whereas when CB sprays were applied with and without LS and ATS, fruit density was reduced compared to the untreated control treatment. Hand-thinning resulted in lower fruit density and increased percentage of surface red colour and increased fruit surface blush and ground hue compared to the untreated control. All ATS, LS and CB fruit-thinning treatments had similar fruit length-to-width ratios, skin percent red, and ground and blush hue colour.

Return bloom

Thinning treatments had a significant effect on the percentage of spurs with flowers in the spring of 2023 ($P=0.0078$) and 2024 ($P<0.0001$) (Table 12), although return bloom was 24% in 2024 compared to 69% in 2023, averaged across all treatments. The untreated control (59%) had the lowest return bloom, whereas trees treated with LS combined with fruitlet thinning of CB had the highest (80%) in 2023 (treatments applied

in 2022). ATS and LS, with and without fruitlet applications of CB, had similar return bloom as the hand-thinned and untreated controls.

For treatments applied in 2023, return bloom was markedly lower in contrast to 2022 (Table 12). Trees treated with ATS and LS, followed by fruitlet sprays of CB, both had 40% return bloom in comparison with 16% and 14% for the untreated and hand-thinned control treatments, respectively, and 25% for the single fruitlet sprays of CB. ATS and LS alone had similar return bloom to the untreated and hand-thinned control treatments.

Discussion

The primary determinates of thinning efficacy are fruit set, crop load, fruit weight, and level of return bloom the following season (the latter being a proxy for biennial bearing). When evaluating the key objectives of this trial, LS combined with mineral oil provided a slightly greater thinning response (as measured by reducing fruit set) in the years when it was effective compared to ATS, although results were variable across years and cultivars. When ATS and LS were combined with fruitlet sprays of CB and 6-BA (Gala) or CB (Honeycrisp), there were marked reductions in fruit set and crop load, indicating the overall thinning response came from the fruitlet sprays. Averaged over all years and cultivars and compared with the untreated control trees, LS combined with mineral oil and ATS treatments reduced fruit set by 29% and 9%, respectively, and reduced crop load by 21% and 13%, respectively.

When considering fruit weight, untreated Gala trees produced commercially acceptable weight sizes in both years. In 2022, fruit weight in untreated Honeycrisp trees exceeded ideal weight (309 g) for most wholesale markets, while in 2023, fruit weight (176 g) was suboptimal because of extremely high crop loads (11.4 fruit per cm² TCSA). In retrospect, thinning was only needed in one of four study years because of low natural fruit set despite adequate flowering at bloom. Return bloom data support this notion: return bloom was high for three years and unacceptably low following the 2023 study year (16%). Moreover, from a financial perspective, the gross crop value of fruit was greatest in the untreated control treatments in all years of the study except 2023. Poor

set in Gala (2020, 2021) and Honeycrisp (2022) was associated with environmental conditions such as cool temperatures lead to poor pollination conditions during the effective pollination period. Such conditions are not uncommon in Southern Ontario, and are an impediment to the general adoption of blossom thinning Ontario apple growing regions.

Notwithstanding the relatively low thinning efficacy of blossom thinners, one inherent risk with thinning at bloom is that crop adjustments are made prior to a clear indication of initial fruit set, and an assessment of the degree of thinning required. In Southern Ontario, environmental conditions such as winter and spring temperatures, pollination, and solar radiation levels can greatly influence bloom levels and initial fruit set. This justifies waiting until fruitlets reach ~5 to 15 mm when they are more sensitive to available chemical fruitlet thinning products.

The purported benefits of thinning early with ATS and LS at bloom to enhance return bloom, in contrast to fruitlet thinning or even hand thinning, were only observed in 2023 for Honeycrisp. This was likely attributable to the early reduction of the percentage of flowering spurs with zero and one fruit (Table 8). Honeycrisp is a biennial cultivar (Robinson et al. 2009), likely because it undergoes flower induction and initiation early in the growing season (Clements and Cowgill 2020; Tromp 2000). For this reason, in years of heavy natural fruit set, reducing crop load during bloom and early fruit development should increase flower initiation and enhance return bloom. The data in this study support this premise. In 2023, hand thinning resulted in only 13% return bloom, and fruitlet thinners resulted in 25% return bloom. However, when combined with either ATS or LS, fruitlet thinners had 40% return bloom even though final crop loads for these treatments were similar at harvest.

It can be problematic to compare blossom thinning studies because tree and thinning responses can vary due to factors such as environmental conditions, cultivars, tree age, pollination conditions, pollinator activity, thinning products, rates, and methods of application. However, there are several studies in the horticultural literature that have previously investigated LS and ATS in other apple production regions. ATS is used commercially as an apple blossom thinner in the United States, Europe, Australia, and

New Zealand (Kon and Schupp 2018) and to a much lesser extent in Canada. The Canadian pesticide regulator (PMRA) requires blossom-thinning agents be registered as pesticides; however, there are currently no such registered ATS derivative products. As a workaround, growers will apply ATS as a foliar fertilizer during bloom at a rate of 2-4% (v/v) (Musacchi and Greene 2017). Byers and Lyons (1985) were some of the first to evaluate ATS and found that it desiccated floral parts when applied at bloom. Subsequent work on apple (Byers 1997) indicated that ATS inhibited fruit set, but applications made in the later stages of bloom (90% open flowers) caused more fruit russetting. ATS also caused more injury to petals, leaves, and new shoots than the other blossom thinners evaluated. Joundi and Flore (2005) investigated ATS as a function of concentration, drying time, and flower development stage and found that ATS-induced flower damage increased as the drying time of the ATS spray increased. Moreover, 2% ATS resulted in elevated levels of flower damage regardless of drying time, and fully developed open flowers were more susceptible to ATS damage than closed flowers. In a Brazilian study, De Ross Marchioretto et al. (2018) found that ATS reduced *in vitro* pollen germination and caused more damage to the stigmas/styles than 2.5% LS. In the orchard, ATS was effective at reducing the crop load of Fuji trees when applied at 90% full bloom, although the thinning response was mild. In a Canadian study on Ambrosia and Aurora Golden Gala™, Hamson and Bedford (2011) found that 1.6% ATS reduced initial fruit set, but follow-up hand thinning was required.

LS has been also used commercially as an apple blossom thinner in many apple growing regions, especially when required for certified organic apple production. One advantage of LS in contrast to other blossom thinners is its bimodal action to both inhibit pollen tube growth as well as impede photosynthesis (McArtney et al. 2006).

Reductions in photosynthesis can reduce fruit set when fruitlets are in a carbon deficit state (Robinson et al 2016); it can also reduced fruit size at harvest if the reduction is significant and for an extended period (Bhusal et al 2016). In a study conducted in British Columbia, Canada, Guak et al. (2002) found LS reduced the crop load of Fuji and Gala trees when applied at 85% full bloom at rates with a linear response up to 4%. For Fuji, the highest LS rate was about as effective as the 1.6% ATS commercial control in terms of reduced fruit set. However, it increased the proportion of fruiting sites with a

single fruit and increased fruit weight at harvest. For Gala, 3-4% LS also showed positive thinning effects but proved less effective than 1.6% ATS. In a study conducted in New York, USA, Peck et al. (2017) found that LS with mineral oil (rates unspecified) reduced crop load compared with the untreated trees but induced fruit russetting. DeLong et al. (2018) observed that a combination of LS and mineral oil or fish oil was highly effective at reducing the crop load of Gingergold. In a study conducted in Washington, USA, Yoder et al. (2013) found that blossom sprays of LS combined with fish oil were effective at reducing crop loads for Gala and Golden Delicious trees. In a New Zealand study on Braeburn, three bloom applications of 2% LS reduced initial and final fruit set by 39% and 34%, respectively (McArtney et al. 2006). Moreover, in investigating the mode of action, the study demonstrated that LS inhibited pollen tube growth and fertilization and depressed photosynthesis in spur leaves, which were both believed to contribute to reduced fruit set. Kon et al. (2018) found that two blossom applications of LS combined with mineral oil reduced fruit set and crop load of Golden Delicious but not Gala trees. In contrast, ATS was effective in reducing initial fruit set in both Golden Delicious and Gala trees but failed to reduce crop load. In a Korean study on RubyS apple trees, Myo Win et al. (2022) found that LS applied at one and three days after full bloom decreased crop load and improved several quality parameters. Yoo et al. (2016) found three bloom applications of 100 mg·L⁻¹ LS reduced fruit set of Gamhong apples by 66% and concluded that a single application was sufficient. Bound (2010) found that 2% LS reduced crop load in Gala apples by 40%, and adding an adjuvant increased the thinning effect up to 80%.

Consideration of Blossom Thinning Timing with and without the PTGM

ATS and LS blossom thinner application times were informed by the proprietary PTGM (Peck and Olmstead 2018; Yoder et al. 2013). There are a number of limitations when using the PTGM. Firstly, the model does not account for bee/pollinator activity and assumes pollination occurs when the target number of flowers have opened. Secondly (and importantly), due to rainy or windy weather, blossom thinning products cannot always be applied at the precise time recommended by the model. Yoder et al. (2013) found that cultivars differ in style length and the growth rates of pollen tubes in response

to environmental conditions. Further work by DeLong et al. (2016) showed that paternal pollen tube growth rates are affected by maternal cultivar and temperature. Hence, cultivar specific PTGMs are required and need to be adjusted seasonally. Thirdly, the model does not account for flower competence (e.g., frost injury which could naturally reduce crop load), so growers need to be aware of situations where natural fruit set may be reduced. In the absence of the PTGM, Allen et al. (2021) demonstrated a simpler yet equally efficacious approach. This involves applying the first blossom thinner when 20% of flowers are open, followed by a second application within 48 h (but extended up to 72 h when lower temperatures are experienced).

Product Costs

From a commercial perspective, the cost of blossom-thinning products outlined in this study should be considered in the context of any thinning program and weighed against the benefits of thinning efficacy, reliability, and consistency. The thinning treatments in this study varied significantly in product costs (Table 13). The CB fruitlet treatment was least expensive, followed by ATS, then LS combined with mineral oil. While there may be added fungicidal benefits of using LS, this study suggests the costs of blossom thinning with LS, which are approximately \$1,114/ha (assuming two sprays of 1000 L/ha), may outweigh its thinning benefits. Blossom thinning with ATS is clearly more cost-effective, with a lower cost of \$343/ha (assuming two sprays of 1000 L/ha), but consistent efficacy was not observed in this study. Towards this end, future work should investigate whether concentrations of ATS higher than 2% (v/v) will provide adequate thinning when applied at bloom, without causing phytotoxicity to the sensitive developing spur leaves and fruit. Another approach is to develop safe, dependable, and cost-effective blossom-thinning chemicals to use in precision-thinning spray programs where sequential thinners are applied to reduce crop load. This would be especially useful for biennial cultivars like Honeycrisp that benefit from early thinning.

The results of this and all thinning studies should be interpreted with caution because annual variations in the tree response to thinning can occur. Moreover, cultivars may respond differently to blossom thinning compounds at the rates used in this study.

Summary

Blossom thinning with 2% LS combined with 2% mineral oil or 2% ATS provided mild but inconsistent thinning in this study. However, it did provide a 15% reduction in crop load in Honeycrisp in the year where fruit set was heavy. Mild leaf phytotoxicity was observed with no fruit russetting. The PTGM model was used to guide timing of blossom sprays and was straightforward to use. Overall, the benefits of early crop load reduction using LS and ATS blossom thinners need to be balanced with product costs, potential mild response, risk of frost, leaf phytotoxicity, and fruit russetting. Future research should focus on investigating higher concentrations of the more cost-effective blossom thinner ATS, in particular, without inducing leaf phytotoxicity or fruit russet. Furthermore, the development of safe, reliable, and cost-effective blossom-thinning chemicals to use in precision-thinning spray programs are warranted. This is especially the case for biennial cultivars like Honeycrisp. Potential candidates include potassium thiosulphate (Bound and Wilson 2004), potassium bicarbonate, and sodium chloride (Bound, 2010).

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this study.

CRediT statement

JAC conceptualized and planned the experiment and developed the methodology. AB collected and curated the data. EB assisted with running the pollen tube growth model and measuring pollen tube lengths. CB and JAC conducted the statistical analyses. JAC wrote the original draft while CB assisted with editing. JAC secured funding or provided project management.

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Data Availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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Figure Captions

Figure 1. Fruit set of Gala trees in 2020 (A) and 2021 (B) in response to 2% ammonium thiosulphate (ATS) and 2.5% lime sulphur (LS) tank mixed with 2% mineral oil applied at bloom, with or without fruitlet (fruit) thinning sprays of carbaryl and 6-benzyladenine (6-BA), and fruitlet thinning sprays of carbaryl and 6-benzyladenine (6-BA) alone applied postbloom (fruit). Data represent the lsmeans. Mean values with the same letter are not significantly different according to Tukey's HSD test ($P=0.05$).

Figure 2. Crop load of Gala trees in 2020 (A) and 2021 (B) in response to 2% ammonium thiosulphate (ATS) and 2.5% lime sulphur (LS) tank mixed with 2% mineral oil applied at bloom, with or without fruitlet (fruit) thinning sprays of carbaryl and 6-benzyladenine (6-BA), and fruitlet thinning sprays of carbaryl and 6-benzyladenine (6-BA) alone applied postbloom (fruit). Data represent the lsmeans. Mean values with the same letter are not significantly different according to Tukey's HSD test ($P=0.05$).

Figure 3. Fruit set of Honeycrisp trees in 2022 (A) and 2023 (B) in response to 2% ammonium thiosulphate (ATS) and 2.5% lime sulphur (LS) tank mixed with 2% mineral oil applied at bloom, with or without fruitlet (fruit) thinning sprays of carbaryl and 6-benzyladenine (6-BA), and fruitlet thinning sprays of carbaryl and 6-benzyladenine (6-BA) alone applied postbloom (fruit). Data represent the lsmeans. Mean values with the same letter are not significantly different according to Tukey's HSD test ($P=0.05$).

Figure 4. Crop load of Honeycrisp trees in 2022 (A) and 2023 (B) in response to 2% ammonium thiosulphate (ATS) and 2.5% lime sulphur (LS) tank mixed with 2% mineral oil applied at bloom, with or without fruitlet (fruit) thinning sprays of carbaryl and 6-benzyladenine (6-BA), and fruitlet thinning sprays of carbaryl and 6-benzyladenine (6-BA) alone applied post bloom (fruit). Data represent the lsmeans. Mean values with the same letter are not significantly different according to Tukey's HSD test ($P=0.05$).

Table 1. Flower phenology dates, target fruit number, the predicted date/time to apply blossom thinner sprays using the pollen tube growth model (PTGM) , and date when fruitlet sprays were applied.

Stage	Gala		Honeycrisp	
	2020	2021	2022	2023
First pink	18-May	27-Apr	09-May	03-May
Dates of full bloom	25-May	10-May	19-May	15-May
Target number of fruit per tree ^a	44	53	29	74
Target kings flowers open based on PTGM model	23-May 5:00 PM	05-May 12:00 AM	15-May 8:00 AM	16-May 12:00 PM
Actual date/time of first blossom thinner	25-May 8:00 PM	13-May 8:00 AM	15-May 11:00 AM	16-May 8:00 AM
PTGM forecasted second blossom thinner	28-May 5:00 AM	16-May 7:00 PM	17-May 11:00 AM	20-May 10:00 AM
Actual date/time of second blossom thinner	27-May 2:00 PM	16-May 8:00 PM	17-May 10:47 AM	21-May 8:00 AM
Hours between first and second blossom thinning spray	42	84	48	120
Carbaryl fruitlet spray (~10 mm king fruit diameter)	09-Jun	30-May	02-Jun	30-May
Date of hand thinning	08-Jul	13-Jul	17-Jul	07-Jul

Note: ^a determined by estimating average tree trunk cross-sectional area multiplied by six

Table 2. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA), on fruit set of Brookfield Gala/M.9 T337 apple trees in 2020 and 2021.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Percentage of flowering spurs with indicated number of fruit							
		0		1		2		3	4
2020									
Untreated Control	-	72.9	b	26.8	a	0.3		0.0	0.0
Hand-thinned control	-	75.9	b	23.6	a	0.5		0.0	0.0
-	1500 CB + 75 6-BA	87.9	ab	11.8	ab	0.4		0.0	0.0
2% ATS	-	73.8	b	25.3	a	0.9		0.0	0.0
2.5% LS + 2% (v/v) mineral oil	-	83.3	ab	16.1	ab	0.6		0.0	0.0
2% ATS	1500 CB + 75 6-BA	83.3	ab	16.4	ab	0.3		0.0	0.0
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	96.3	a	3.7	b	0.0		0.0	0.0
<i>P</i> value		0.0008		0.0009		0.5327		-	-
Contrasts									
Bloom thinning vs fruitlet thinning		*		*		ns		-	-
Bloom thinning vs bloom + fruitlet thinning		**		**		ns		-	-
2021									
Untreated control	-	65.8	c	31.2	a	2.7	ab	0.0	0.3
Hand-thinned control	-	65.1	c	29.2	a	5.6	a	0.1	0.0
-	1500 CB + 75 6-BA	84.3	ab	14.2	bc	1.2	ab	0.3	0.0
2% ATS	-	75.6	bc	21.8	ab	2.1	ab	0.5	0.0
2.5% LS + 2% (v/v) mineral oil	-	68.5	c	27.8	a	3.7	ab	0.0	0.0
2% ATS	1500 CB + 75 6-BA	94.5	a	5.3	c	0.2	b	0.0	0.0
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	91.4	a	8.6	c	0.0	b	0.0	0.0
<i>P</i> value		<0.0001		<0.0001		0.0142		0.3426	0.4481
Contrasts									
Bloom thinning vs fruitlet thinning		**		**		ns		ns	ns
Bloom thinning vs bloom + fruitlet thinning		***		***		*		ns	ns

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied on 26 and 27 May 2020, 13 and 17 May 2021; fruitlet thinning sprays on 9 June 2020 (average king 12.9 mm, lateral 10.8 mm) and 30 May 2021 (average king 11.2 mm, lateral 9.1 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart

Table 3. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA), on harvest parameters of Brookfield Gala/M.9 T337 apple in 2020 and 2021.

						Total				Economic		Gross			
		Fruitlet thinner (mg L ⁻¹)		Total fruit yield (kg/tree)		Marketable yield (kg/tree)		number of fruit (no/tree)		Mean fruit weight (g)		return (\$/tree)		value of fruit (\$/ha)	
Blossom thinning ^a		1)													
2020															
Untreated Control	-	8.4	a	7.9	a	46	a	182	a	9.18	a	10,204	a		
Hand-thinned control	-	5.5	ab	5.2	ab	30	ab	184	a	6.19	ab	6,879	ab		
-	1500 CB + 75 6-BA	3.8	bc	3.6	bc	21	bc	174	ab	4.07	bc	4,523	bc		
2% ATS	-	5.9	ab	5.8	ab	32	ab	182	a	7.03	ab	7,811	ab		
2.5% LS + 2% (v/v) mineral oil	-	3.7	bc	3.6	bc	22	bc	167	ab	4.07	bc	4,517	bc		
2% ATS	1500 CB + 75 6-BA	2.9	bc	2.8	bc	16	bc	177	ab	3.42	bc	3,800	bc		
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	0.6	c	0.5	c	4	c	137	b	0.66	c	728	c		
<i>P</i> value		<0.0001		<0.0001		<0.0001		0.0339		<0.0001		<0.0001			
Contrasts															
Bloom thinning vs fruitlet thinning		ns		ns		ns		ns		ns		***			
Bloom thinning vs bloom + fruitlet thinning		**		***		***		ns		**		***			
2021															
Untreated control	-	14.6	a	13.4	a	85	a	174	c	14.21	a	15,784	a		
Hand-thinned control	-	11.4	a	10.2	ab	62	a	186	abc	11.51	ab	12,787	ab		
-	1500 CB + 75 6-BA	10.4	a	9.9	abc	56	ab	190	abc	11.59	ab	12,875	ab		
2% ATS	-	10.9	a	10.5	a	56	ab	197	abc	12.26	a	13,626	a		
2.5% LS + 2% (v/v) mineral oil	-	12.2	a	11.4	a	70	a	175	bc	12.48	a	13,864	a		
2% ATS	1500 CB + 75 6-BA	5.0	b	4.9	c	24	c	211	a	6.07	b	6,742	b		
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	5.4	b	5.2	bc	27	bc	201	ab	6.09	b	6,768	b		
<i>P</i> value		<0.0001		<0.0001		<0.0001		0.0017		0.0006		0.0006			
Contrasts															
Bloom thinning vs fruitlet thinning		ns		ns		ns		ns		ns		ns			
Bloom thinning vs bloom + fruitlet thinning		***		***		***		**		***		***			

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied on 26 and 27 May 2020, 13 and 17 May 2021; fruitlet thinning sprays on 9 June 2020 (average king 12.9 mm, lateral 10.8 mm) and 30 May 2021 (average king 11.2 mm, lateral 9.1 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart

Table 4. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA), on the weight of fruit per count size of Brookfield Gala/M.9 T337 apples in 2020 and 2021.

		Fruitlet thinner (mg L ⁻¹) ¹⁾		kg fruit per tree in each size category ^b																		
Blossom thinning ^a				64	72	80	88	100	113	125	138	150	163	175	198	216						
				2020																		
Untreated Control	-			0.16	0.59	ab	1.68	a	3.33	a	1.73	a	0.60	a	0.21	a	0.08	a	0.00	0.00	0.01	0.01
Hand-thinned control	-			0.24	1.03	a	0.99	ab	1.74	bc	0.84	ab	0.42	ab	0.11	a	0.04	a	0.03	0.00	0.01	0.02
-	1500 CB + 75 6-BA			0.16	0.92	ab	0.78	ab	0.87	bc	0.48	b	0.23	ab	0.09	a	0.00	a	0.00	0.01	0.01	0.00
2% ATS	-			0.09	0.83	ab	1.60	a	1.85	ab	1.20	ab	0.27	ab	0.04	a	0.00	a	0.00	0.00	0.00	0.00
2.5% LS + 2% (v/v) mineral oil	-			0.08	0.16	ab	0.65	ab	1.20	bc	0.88	ab	0.52	ab	0.20	a	0.09	a	0.01	0.02	0.00	0.00
2% ATS	1500 CB + 75 6-BA			0.22	0.57	ab	0.67	ab	0.87	bc	0.37	b	0.15	ab	0.01	a	0.00	a	0.03	0.00	0.01	0.02
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA			0.02	0.10	b	0.13	b	0.15	c	0.10	b	0.03	b	0.01	a	0.00	a	0.00	0.00	0.00	0.00
<i>P</i> value				0.6549	0.0236		0.0045		<0.0001		0.0029		0.0168		0.0379		0.0318		0.3518	0.1162	0.7848	0.3025
Contrasts																						
Bloom thinning vs fruitlet thinning				ns	ns		ns		ns		ns		ns		ns		ns		ns	ns	ns	
Bloom thinning vs bloom + fruitlet thinning				ns	ns		*		**		**		*		ns		ns		ns	ns	ns	
2021																						
Untreated control	-			0.00	a	0.00	b	0.12	b	1.27	4.69	a	4.60	a	2.46	a	0.85		0.52	0.07	0.03	0.00
Hand-thinned control	-			0.00	a	0.17	ab	0.80	ab	1.76	3.74	ab	2.82	ab	1.34	ab	0.60		0.08	0.06	0.00	0.00
-	1500 CB + 75 6-BA			0.00	a	0.23	ab	1.76	a	1.91	3.07	ab	1.93	bcd	0.74	ab	0.63		0.11	0.02	0.00	0.00
2% ATS	-			0.00	a	0.04	ab	0.81	ab	2.38	4.10	ab	2.52	bc	0.74	ab	0.28		0.03	0.00	0.00	0.02
2.5% LS + 2% (v/v) mineral oil	-			0.00	a	0.00	b	0.62	ab	1.58	4.09	ab	3.30	ab	1.80	ab	0.60		0.20	0.03	0.03	0.00
2% ATS	1500 CB + 75 6-BA			0.07	a	0.41	a	1.14	ab	1.42	1.04	b	0.48	d	0.23	b	0.11		0.06	0.00	0.00	0.02
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA			0.00	a	0.19	ab	0.95	ab	1.13	1.56	ab	0.75	cd	0.47	b	0.22		0.09	0.02	0.01	0.00
<i>P</i> value				0.0401	0.0340		0.0823		0.4657		0.0068		<0.0001		0.0061		0.2973		0.2851	0.5915	0.6485	0.5520
Contrasts																						
Bloom thinning vs fruitlet thinning				ns	ns		*		ns		ns		ns		ns		ns		ns	ns	ns	
Bloom thinning vs bloom + fruitlet thinning				*	**		ns		***		***		*		ns		ns		ns	ns	ns	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied on 26 and 27 May 2020, 13 and 17 May 2021; fruitlet thinning sprays on 9 June 2020 (average king 12.9 mm, lateral 10.8 mm) and 30 May 2021 (average king 11.2 mm, lateral 9.1 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

^b Fruit diameter equivalents for each count size: 64 = 92-95 mm, 72 = 89-92 mm, 80 = 84.5-89 mm, 88 = 83-84.5 mm, 100 = 79-83 mm, 113 = 76-79 mm, 125 = 73-76 mm, 138 = 70-73 mm, 150 = 67-70 mm, 163 = 64-67 mm, 175 = 60-64 mm, 198 = 57-60 mm, 216 = <57 mm.

Table 5. Severity of phytotoxicity on 18 June 2020 following applications of ammonium thiosulphate (ATS) and lime sulphur (LS) as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA), on Brookfield Gala/M.9 T337 apple trees in 2020.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Leaf curling (1=present, 0=absent)	Severity of leaf curling (0=none, 1=very slight, 2=slight, 3=moderate, 4=high, 5=very high)	Leaf necrosis (1=present, 0=absent)	Severity of leaf necrosis (0=none, 1 = very slight, 2=slight, 3=moderate, 4=high, 5=very high)		
Untreated Control	-	1.0	1.0	0.5	a	0.5	c
Hand-thinned control	-	1.0	1.0	0.7	a	0.7	bc
-	1500 CB + 75 6-BA	1.0	1.1	0.7	a	0.7	bc
2% ATS	-	1.0	1.3	1.0	a	1.8	a
2.5% LS + 2% (v/v) mineral oil	-	1.0	1.2	1.0	a	1.4	ab
2% ATS	1500 CB + 75 6-BA	1.0	1.2	1.0	a	2.1	a
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	1.0	1.0	1.0	a	1.3	abc
<i>P</i> value		-	0.3977	0.0170		<0.0001	
Contrasts							
Bloom thinning vs fruitlet thinning		-	ns	*		***	
Bloom thinning vs bloom + fruitlet thinning		-	ns	ns		ns	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied on 26 and 27 May 2020 (full bloom), fruitlet thinning sprays on 9 June 2020 (average king 12.9 mm, lateral 10.8 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart

Table 6. Severity of phytotoxicity following applications of ammonium thiosulphate (ATS) and lime sulphur (LS) as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA), in 2021 on Brookfield Gala/M.9 T337 apple trees.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Leaf necrosis (1=present, 0=absent)						Severity of leaf necrosis (0=none, 1=very slight, 2=slight, 3=moderate, 4=high, 5=very high)									
		27 May	1 June	8 June	11 June	16 June		27 May	1 June	8 June	11 June	16 June					
Untreated control	-	1.0	1.0	1.0	0.6	0.4	b	1.0	b	1.0	b	1.0	b	0.7	c	0.4	b
Hand-thinned control	-	1.0	1.0	1.0	0.9	0.9	ab	1.0	b	1.0	b	1.0	b	0.9	bc	0.9	ab
-	1500 CB + 75 6-BA	1.0	1.0	1.0	0.8	0.8	ab	1.0	b	1.0	b	1.0	b	0.8	bc	0.8	ab
2% ATS	-	1.0	1.0	1.0	1.0	1.0	a	1.8	a	1.9	a	1.8	a	1.5	ab	1.0	a
2.5% LS + 2% (v/v) mineral oil	-	1.0	1.0	1.0	1.0	1.0	a	1.5	ab	1.4	ab	1.1	b	1.4	abc	1.0	a
2% ATS	1500 CB + 75 6-BA	1.0	1.0	1.0	1.0	0.8	ab	1.4	ab	1.7	a	1.8	a	1.7	a	0.8	ab
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	1.0	1.0	1.0	1.0	0.9	ab	1.4	ab	1.6	ab	1.3	b	1.0	abc	0.9	ab
<i>P</i> value		-	-	-	0.0839	0.0488		0.0015	0.0002	<0.0001		0.0007				0.0488	
Contrasts																	
Bloom thinning vs fruitlet thinning		ns	ns	ns	ns	ns		***	**	**		**				ns	
Bloom thinning vs bloom + fruitlet thinning		ns	ns	ns	ns	ns		ns	ns	ns		ns				ns	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied at full bloom on 13 May and repeated on 17 May 2021, fruitlet thinning sprays were applied on 30 May 2021 (average king 11.2 mm, lateral 9.1 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart

Table 7. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB) and 6-benzyladenine (6-BA) on return bloom in 2021 and 2022 for treatments applied in 2020 and 2021 on Brookfield Gala/M.9 T337 apple trees.

	Fruitlet thinner (mg L ⁻¹)	Percent of flowering spurs			
Blossom thinning ^a	¹⁾	Spring 2021		Spring 2022	
Untreated Control	-	76.1	b	58.6	b
Hand-thinned control	-	85.5	ab	67.8	ab
-	1500 CB + 75 6-BA	92.3	a	79.0	ab
2% ATS	-	79.4	b	74.5	ab
2.5% LS + 2% (v/v) mineral oil	-	80.4	ab	67.0	ab
2% ATS	1500 CB + 75 6-BA	82.3	ab	88.0	a
2.5% LS + 2% (v/v) mineral oil	1500 CB + 75 6-BA	84.7	ab	87.1	a
<i>P</i> value		0.0095		0.0176	
Contrasts					
Bloom thinning vs fruitlet thinning		**		ns	
Bloom thinning vs bloom + fruitlet thinning		ns		*	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied on 26 and 27 May 2020, 13 and 17 May 2021; fruitlet thinning sprays on 9 June 2020 (average king 12.9 mm, lateral 10.8 mm) and 30 May 2021 (average king 11.2 mm, lateral 9.1 mm). The hand-thinned control trees were thinned by hand on 8-July 2020 and 13-July 2021 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Table 8. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB), on fruit set in 2022 and 2023 of Honeycrisp/Bud 9 apple trees.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Percentage of flowering spurs with indicated number of fruit								
		0	1	2	3	4	5			
2022										
Untreated control	-	25.4	ab	49.2	19.2	ab	6.0	0.0	0.0	
Hand-thinned control	-	26.9	ab	43.7	23.5	ab	4.2	1.3	0.0	
-	1500 CB	21.2	b	47.1	25.0	a	5.3	0.7	0.7	
2% ATS	-	40.6	ab	41.6	14.9	ab	2.6	0.5	0.0	
2.5% LS + 2% (v/v) mineral oil	-	51.7	a	39.3	7.2	b	1.5	0.4	0.0	
2% ATS	1500 CB	49.3	ab	36.5	9.0	ab	4.6	0.0	0.5	
2.5% LS + 2% (v/v) mineral oil	1500 CB	45.2	ab	45.3	9.5	ab	0.0	0.0	0.0	
<i>P</i> value		0.0119		0.7778	0.0068		0.3556	0.5606	0.5448	
Contrasts										
Bloom thinning vs fruitlet thinning		**		ns	**		ns	ns	ns	
Bloom thinning vs bloom + fruitlet thinning		ns		ns	ns		ns	ns	ns	
2023										
Untreated control	-	34.4	d	54.8	a	7.9	ab	2.6	0.3	0.0
Hand-thinned control	-	35.7	cd	53.9	ab	9.5	ab	0.8	0.0	0.0
-	1500 CB	53.7	abc	39.7	bc	6.1	ab	0.6	0.0	0.0
2% ATS	-	31.1	d	52.5	ab	12.6	a	3.6	0.1	0.0
2.5% LS + 2% (v/v) mineral oil	-	40.1	bcd	53.1	ab	6.2	ab	0.4	0.3	0.0
2% ATS	1500 CB	60.9	a	35.3	c	3.5	b	0.3	0.0	0.0
2.5% LS + 2% (v/v) mineral oil	1500 CB	55.7	ab	41.9	abc	2.1	b	0.4	0.0	0.0
<i>P</i> value		<0.0001		0.0003	0.0068		0.0785	0.2885	-	
Contrasts										
Bloom thinning vs fruitlet thinning		***		**	ns		ns	ns	-	
Bloom thinning vs bloom + fruitlet thinning		***		***	**		ns	ns	-	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied at full bloom on 15 and 18 May 2022, 16 and 21 May 2023; fruitlet thinning sprays were applied on 2 June 2022 (average king 12.1 mm, lateral 9.4 mm) and 30 May 2023 (average king 12.9 mm). The hand-thinned control trees were thinned by hand on 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Table 9. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB), on harvest parameters of Honeycrisp/Bud 9 apple in 2022 and 2023.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Total fruit yield (kg/tree)	Marketable yield (kg/tree)	Total number of fruit (no/tree)	Mean fruit weight (g)	Economic return (\$/tree)	Gross value of fruit (\$/ha)
2022							
Untreated control	-	12.5	10.5	42	a	309	ND
Hand-thinned control	-	7.2	6.4	24	b	297	ND
-	1500 CB	9.1	8.2	30	ab	313	
2% ATS	-	9.8	8.4	33	ab	307	
2.5% LS + 2% (v/v) mineral oil	-	8.5	7.5	26	ab	337	
2% ATS	1500 CB	7.4	6.4	24	b	310	
2.5% LS + 2% (v/v) mineral oil	1500 CB	8.5	6.6	29	ab	296	
<i>P</i> value		0.0788	0.0923	0.0314	0.5879		
Contrasts							
Bloom thinning vs fruitlet thinning		ns	ns	ns	ns		
Bloom thinning vs bloom + fruitlet thinning		ns	ns	ns	ns		
2023							
Untreated control	-	16.7	9.3	97	ab	176	c
Hand-thinned control	-	17.7	14.8	80	b	225	a
-	1500 CB	19.4	12.5	89	ab	222	ab
2% ATS	-	20.9	14.6	120	a	175	c
2.5% LS + 2% (v/v) mineral oil	-	18.3	11.7	103	ab	179	bc
2% ATS	1500 CB	20.9	16.3	86	b	245	a
2.5% LS + 2% (v/v) mineral oil	1500 CB	19.4	15.6	89	ab	224	a
<i>P</i> value		0.3051	0.1195	0.0113	<0.0001	0.0158	0.0158
Contrasts							
Bloom thinning vs fruitlet thinning		ns	ns	*	***	ns	ns
Bloom thinning vs bloom + fruitlet thinning		ns	ns	**	***	**	**

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively. ND = no data.

^a Blossom thinning sprays applied at full bloom on 15 and 18 May 2022, 16 and 21 May 2023; fruitlet thinning sprays were applied on 2 June 2022 (average king 12.1 mm, lateral 9.4 mm) and 30 May 2023 (average king 12.9 mm). The hand-thinned control trees were thinned by hand on 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Table 10. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without a fruitlet thinning spray of carbaryl (CB), on the weight of fruit per count size of Honeycrisp/Bud 9 apples in 2023.

		kg fruit per tree in each size category ^b																				
	Fruitlet thinner (mg L ⁻¹)	48	56	64	72	80	88	100	113	125	138	150	163	175	198	216						
Blossom thinning ^a																						
Untreated control	-	0.00	0.29	ab	1.15	1.47	ab	1.86	2.07	2.85	2.69	abc	1.37	ab	1.29	ab	0.75	0.53	a	0.22	0.08	0.05
Hand-thinned control	-	0.07	0.47	ab	2.20	3.06	ab	3.66	2.71	2.56	1.66	abc	0.70	ab	0.38	ab	0.20	0.03	a	0.02	0.00	0.00
-	1500 CB	0.00	0.47	ab	2.31	3.51	ab	4.52	2.96	2.80	1.52	abc	0.77	ab	0.31	ab	0.12	0.08	a	0.05	0.00	0.00
2% ATS	-	0.00	0.49	ab	1.35	2.11	ab	2.40	2.48	3.23	3.70	a	2.17	a	1.55	a	0.57	0.38	a	0.27	0.00	0.17
2.5% LS + 2% (v/v) mineral oil	-	0.00	0.00	b	0.72	1.10	b	2.45	3.58	4.29	3.13	ab	1.60	ab	0.81	ab	0.41	0.03	a	0.07	0.04	0.04
2% ATS	1500 CB	0.18	2.77	a	3.68	5.05	a	3.86	2.16	1.78	0.59	c	0.53	ab	0.03	b	0.15	0.08	a	0.03	0.00	0.00
2.5% LS + 2% (v/v) mineral oil	1500 CB	0.00	0.91	ab	2.91	5.03	a	3.39	2.37	2.58	1.33	bc	0.45	b	0.29	ab	0.11	0.06	a	0.00	0.00	0.00
P value		0.1190	0.0302		0.0609	0.0090		0.1342	0.3618	0.1501	0.0011		0.0243	0.0221		0.0874	0.0404		0.2304	0.1115	0.1196	
Contrasts																						
Bloom thinning vs fruitlet thinning		ns	ns	ns	ns	*	ns	ns	**	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bloom thinning vs bloom + fruitlet thinning		ns	**	**	***	ns	ns	*	***	***	**	*	ns	ns	ns	ns	ns	ns	ns	ns	*	*

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied at full bloom on 16 May and repeated on 21 May 2023, fruitlet thinning sprays were applied on 30 May 2023 (average king 12.9 mm). The hand-thinned control trees were thinned by hand on 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

^b Fruit diameter equivalents for each count size: 48 = >98, 56 = 95-98 mm, 64 = 92-95 mm, 72 = 89-92 mm, 80 = 84.5-89 mm, 88 = 83-84.5 mm, 100 = 79-83 mm, 113 = 76-79 mm, 125 = 73-76 mm, 138 = 70-73 mm, 150 = 67-70 mm, 163 = 64-67 mm, 175 = 60-64 mm, 198 = 57-60 mm, 216 = <57 mm.

Table 11. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without a fruitlet thinning spray of carbaryl (CB), on fruit quality in 2023 of Honeycrisp/Bud 9 apple trees.

	Fruitlet thinner (mg L ⁻¹)	Fruit density (g/cm ³)		Length to width ratio	Skin percent red (%)		Skin ground hue		Skin blush hue	
Blossom thinning ^a										
Untreated control	-	0.800	a	1.036	51.5	b	118.4	b	171.7	b
Hand-thinned control	-	0.781	b	1.036	73.6	a	126.7	a	176.8	a
-	1500 CB	0.786	ab	1.036	60.1	b	120.8	b	173.9	ab
2% ATS	-	0.796	ab	1.038	52.3	b	117.4	b	172.1	b
2.5% LS + 2% (v/v) mineral oil	-	0.791	ab	1.037	49.3	b	118.2	b	171.3	b
2% ATS	1500 CB	0.783	b	1.038	57.3	b	120.6	b	173.6	ab
2.5% LS + 2% (v/v) mineral oil	1500 CB	0.783	b	1.037	55.8	b	120.5	b	172.8	b
<i>P</i> value		0.0031		0.0881	<0.0001		<0.0001		0.0006	
Contrasts										
Bloom thinning vs fruitlet thinning		ns		ns	*		*		*	
Bloom thinning vs bloom + fruitlet thinning		**		ns	ns		**		ns	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at $P=0.05$. ns, *, **, ***, indicates not significant, and significant differences at $P=0.05$, $P=0.01$, and $P=0.001$ respectively.

^a Blossom thinning sprays applied at full bloom on 16 May 2023 and repeated on 21 May, fruitlet thinning sprays were applied on 30 May 2023 (average king 12.9 mm). The hand-thinned control trees were thinned by hand on 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Table 12. Influence of ammonium thiosulphate (ATS) and lime sulphur (LS) applied as blossom thinning treatments, with or without fruitlet thinning sprays of carbaryl (CB), on return bloom in 2023 and 2024 for treatments applied in 2022 and 2023 on Honeycrisp/Bud 9 apple trees.

Blossom thinning ^a	Fruitlet thinner (mg L ⁻¹)	Percent of flowering spurs			
		2023		2024	
Untreated control	-	59	b	16	b
Hand-thinned control	-	65	ab	13	b
-	1500 CB	73	ab	25	ab
2% ATS	-	64	ab	18	b
2.5% LS + 2% (v/v) mineral oil	-	65	ab	13	b
2% ATS	1500 CB	76	ab	40	a
2.5% LS + 2% (v/v) mineral oil	1500 CB	80	a	40	a
<i>P</i> value		0.0078		<0.0001	
Contrasts					
Bloom thinning vs fruitlet thinning		ns		ns	
Bloom thinning vs bloom + fruitlet thinning		**		***	

Note: Mean values with the same letter within a given column are not significantly different according to Tukey's HSD test at *P*=0.05. ns, *, **, ***, indicates not significant, and significant differences at *P*=0.05, *P*=0.01, and *P*=0.001 respectively.

^a Blossom thinning sprays applied at full bloom on 15 and 18 May 2022, 16 and 21 May 2023; fruitlet thinning sprays were applied on 2 June 2022 (average king 12.1 mm, lateral 9.4 mm) and 30 May 2023 (average king 12.9 mm). The hand-thinned control trees were thinned by hand on 17-July 2022, and 7-July 2023 by removing all but one fruit per cluster and spacing fruit ~10 cm apart.

Table 13. Approximate cost (\$/1000 L spray solution) for spray materials for each of the blossom and fruitlet thinning treatments. Based on list cost as of August 2025.

Thinning treatment	Fruitlet thinner treatment	Amount of product (L)/ 1000 L spray	Total cost of spray material (\$/1000 L spray solution)
Untreated control	-	-	-
Hand-thinned control	-	-	-
-	1500 mg/L carbaryl ^b	3.125	\$ 125
2% ATS ^{a,b}	-	20	\$ 343
2.5% LS + 2% (v/v) mineral oil ^{a,b}	-	25, 20	\$ 1,114
2% ATS ^{a,b}	1500 mg/L carbaryl ^b	20	\$ 458
2.5% LS + 2% (v/v) mineral oil ^{a,b}	1500 mg/L carbaryl ^b	25, 20	\$ 1,229
Treatment	Product and Manufacturer	Amount (L/1000 L)	Product cost(\$/L)
Lime sulphur (2.5% v/v)	Lime Sulphur, Loveland Products, Dorchester, ON	25	\$ 14.92
Mineral oil (2% v/v)	Purespray green (13E), Suncor Energy Inc., Mississauga, ON	20	\$ 8.70
Non-ionic surfactant (0.005 % v/v)	Agral 90, Noraac Concepts Inc., Guelph, ON	0.5	\$ 19.60
ATS (12-0-0-26S) (2% v/v)	Oligo-S, Axter Agrosience Inc., Mont-st-Hilaire, QC	20	\$ 8.08
Carbaryl (1500 mg/L) ^c	Sevin XLR, Tessenderlo Kerley Inc., Phoenix, Arizona	3.125	\$ 36.85

Notes: ^a two applications of blossom thinners were required

^b 0.05% Agral 90 included with this treatment

^c Sevin XLR contains 466 g carbaryl/L formulated product.







