

# Impacts of 1-Aminocyclopropane-1-Carboxylic Acid as a Late Post-Bloom Thinner on Fruit Set, Yield, and Fruit Quality in “Gala” and “Fuji” Apples

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## Abstract

A few post-bloom thinners are available for apple (*Malus domestica* Borkh.) and the prospects for additional thinners appear to be limited. Application of blossom thinners may present a risk of overthinning in the areas where weather is less predictable. Thus, we studied the impacts of various rates of 1-aminocyclopropane-1-carboxylic acid (ACC) in three strains of “Fuji” apple and different rates of ACC and one rate of Ethrel in “Buckeye Gala” apple, when fruitlet diameter was about 20 mm, on fruit set, yield and fruit quality attributes at harvest, and return bloom in southwest Idaho in the Intermountain West region, USA. In 2013, application of Ethrel at 300 mg·L<sup>-1</sup> did not affect fruit set, fruit weight, diameter (D), length(L), or L/D ratio 34 days after application, or yield, fruit weight, color, russet, and starch degradation pattern (SDP) at harvest, while application of ACC at 150 mg·L<sup>-1</sup> or higher reduced fruit set by 19% to 34% in “Buckeye Gala” apple. In this cultivar, application of ACC at 350 mg·L<sup>-1</sup> significantly increased fruit weight, diameter and length 34 days after application, and increased fruit weight, color, and SDP at harvest time. Application of ACC at all rates reduced total yield per tree in “Buckeye Gala”. Application of ACC at 300 mg·L<sup>-1</sup> significantly reduced fruit set but applications of 150 mg·L<sup>-1</sup> or 300 mg·L<sup>-1</sup> ACC did not affect yield or quality attributes of “Sun Fuji” apple in Sunny Slope area in 2013. Application of ACC reduced fruit set and slightly increased fruit size in “Top Export Fuji” in 2013. Application of ACC at 600 mg·L<sup>-1</sup> significantly reduced fruit set in “Aztec Fuji” apple in 2014. Application of ACC in a season never reduced bloom density (return bloom) of the next season. Overall, we conclude that ACC is an excellent tool as a late-season post-bloom fruit thinner

and can be effective when applied fruitlet diameter is about 20 mm.

## Keywords

Bio-Regulators, Crop Load Adjustment, Ethylene, Thinning

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## 1. Introduction

Thinning of flower and fruit is a crucial practice as it impacts the size of fruit in the current season and rerun bloom in the following season. Several fruit thinners such as 1-naphthyl-N-methylcarbamate (carbaryl), naphthalene acetic acid (NAA), gibberelin ( $GA_{4+7}$ ) and 6-benzylamino purine have been used for apple trees [1] [2] [3] [4]. After Elgetol lost registration, ammonium thiosulfate (ATS), hydrogen cyanamide (Dormex), endothalic acid (Endothal), perlargonic acid (Thinex), and sulfcarbamide (Wilthin), and Tergitol TMN-6 have been tested on apple and/or stone fruit blossom thinning [5] [6].

Even though these bloom thinners effectively reduced fruit sets of certain apple cultivars, other apple cultivars have shown ineffective thinning results [7] [8].

Carbaryl showed a synergistic effect when used in conjunction with a commercial 6-BA formulation (MaxCel, Valent BioSciences LLC). However, the use of carbaryl faces regulatory concerns in the USA and is banned in certain areas in Europe. Thus, there has been an increasing interest in finding new post bloom thinners for apples.

After it was discovered that the pathway of ethylene biosynthesis is methionine—SAM2—ACC-ethylene [9], various studies were conducted on the regulation of ethylene biosynthesis in fruit and they were reviewed by Yang and Hoffman [10]. They reported that the intact climacteric fruits have little ability to convert S-adenosyl-L-methionine (SAM) to ACC or ACC to ethylene and contain only low amounts of ACC [10]. Internal ethylene concentration, ability to convert 1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene (ethylene-forming enzyme EFE activity), and ACC content in the peel of “Golden Delicious” increased only slightly during fruit maturation on the tree [11]. Treatment of immature apples with  $100 \text{ mg}\cdot\text{L}^{-1}$  ethylene for 24 hours increased EFE activity in the peel tissue but did not induce an increase in ethylene production. This ability of apple peel tissue to respond to ethylene with elevated EFE activity increased exponentially during maturation on the tree [11].

It was reported that “Golden Delicious” apple tissues convert 1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene [12]. McArtney and Obermiller [13] reported that ACC reduced fruit set in “Gale Gala” apple.

McArtney [14] reported that ACC reduced fruit set in “GoldRush” apple, and the response was dose dependent. He also reported that the effects of combining ACC and naphthaleneacetic acid on fruit set in “GoldRush” apple were additive. McArtney [14] suggested that application of  $200 \text{ mg}\cdot\text{L}^{-1}$  ACC when fruit is

about 10 mm in diameter could be a useful chemical thinning treatment for apple fruit. Schupp *et al.* [15] reported that application of ACC at 300 mg·L<sup>-1</sup> to 500 mg·L<sup>-1</sup> to “Golden Delicious” apple, when fruit was 20 mm, reduced fruit set.

Theron *et al.* [16] evaluated ACC on “Laetitia”, “Fortune”, and “African Rose™” plums. ACC consistently reduced the hand-thinning requirement in both seasons in “African Rose™”. In the second season, there was a linear decrease in yield and an increase in fruit size as the ACC rate increased from the low to medium rate before flattening off. They recommended that ACC at a rate of 600 mg·L<sup>-1</sup> for “African Rose™” plum and 400 mg·L<sup>-1</sup> for “Laetitia” plum would be optimal rates.

Valent BioSciences LLC announced registration of a new plant growth regulator, to be marketed under the brand name Accede™, utilizing the active ingredient 1-aminocyclopropane-1-carboxylic acid (ACC) [17].

The objective of this study was to study the impact of ACC as a late post-bloom thinner on fruit set, yield, and fruit quality attributes of “Buckeye Gala”, and “Fuji” apples. This study was conducted during 2013 and 2014 seasons. However, we are publishing those critically useful data today, as the needs for a post-bloom thinner is becoming extremely crucial and leaving the world’s apple growers with very limited choices. We chose “Gala” and “Fuji” in our study as these are the most commercially important cultivars in the western USA.

## 2. Materials and Methods

### 2.1. General Descriptions of Orchard, Treatment and Cultural Practices

The experimental orchards for this study were located in Fruitland, Sunny Slope, and Parma, Idaho, USA. Trees were irrigated with a micro-jet system and trained into a central leader vertical axis. In general, the cultural practices, other than applications of post-bloom thinners were according to the local recommendations [18]. These practices are summarized by application of about 50 to 90 kg nitrogen/ha, calcium sprays throughout the season, and spraying the most environmentally sound non-organic commercial chemicals and/or biological tools for pest, weed, and disease control [18].

In each experimental orchard, 2-butoxyethanol, poloxalene, monopropylene glycol (Regulaid; nonionic surfactant; KALO, Inc. Overland Park, KS) at 500 ul·L<sup>-1</sup> was mixed with ACC and/or Ethrel treatments. Trees in Untreated Control treatments in all experimental orchards of this study only received Regulaid at 500 ul·L<sup>-1</sup> spray at the same time that other post-bloom treatments were applied. Trees were sprayed with a 189 L motorized pump-driven sprayer to deliver solution at the rate of 1870 L·ha<sup>-1</sup> when fruitlet diameter was about 20 mm. All orchards were sprayed with lime sulfur at 5% during 80% to 100% bloom. No post-bloom thinner other than ACC or Ethrel treatments was applied in these

orchards.

## 2.2. Measurements and Hand Thinning

Four branches per tree, each 50- to 65-cm in length with about 1.0 to 2.0 cm diameter were selected and number of flower cluster in each of these tagged branches was counted before blooms were open. At the time of hand thinning in each year (about 20 to 30 days after applications of post bloom thinners, as described for each cultivar), fruit set was calculated as number of fruits in the selected branches/number of flower clusters  $\times$  100. After fruit set measurements, fruits in all trees including Untreated Control were hand-thinned to create a 15-cm spacing among fruits, if they were not already at that spacing after chemical thinning. The reason for hand thinning according to this protocol was that even Untreated Control trees must be hand-thinned to a 15-cm spacing among fruit to follow the existing commercial practice. If fruit spacing was more than 15 cm, they were not hand-thinned any further.

## 2.3. Measurement of Return Bloom

To measure return bloom, four 50 to 65-cm branches per tree on each tree were tagged, and the diameter of each branch at the 50 to 65-cm mark was measured with a digital caliper in mid-March each year. Number of flower cluster within that area in each tagged branch was counted before blooms were open on March 22, 2014 (the year after application of treatments). Return bloom was calculated as the number of flower buds/ branch cross sectional area at the 50 to 65-cm mark.

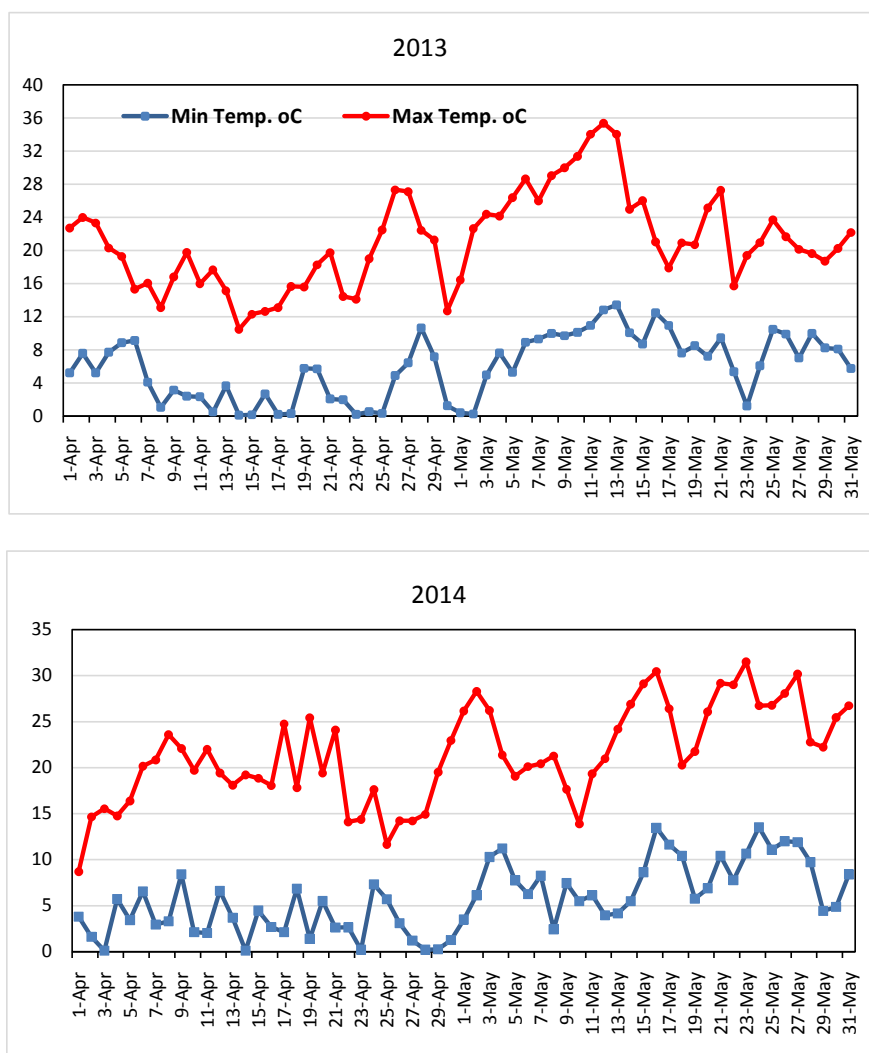
## 2.4. Measurement of Yield and Fruit Quality Attributes

In 2013 and 2014, fruit were harvested at commercial maturity dates as follows: “Buckeye Gala” on Aug. 20, 2013; “Sun Fuji” in Sunnyslope on Oct. 12, 2013; “Top Export Fuji” in Parma on Oct. 14, 2013, and “Aztec Fuji” in Parma on Oct. 16, 2014. Total fruit yield per tree was harvested and recorded in each orchard. Twenty-five fruits per tree were sampled randomly from all sides of the tree and used for quality attributes measurements as described by Fallahi *et al.* [19].

## 2.5. Orchard and Treatments Descriptions in 2013

The maximum and minimum temperature fluctuations in the region during fruit thinner application and fruit set measurements (April and May) were recorded during 2013 and 2014 (**Figure 1**). The following apple orchards and treatments were used in the 2013 experiments:

- 1) “Buckeye Gala”: For this experiment, a seven-year-old orchard, where “Buckeye Gala” trees on RN-29 rootstock were planted at  $1.8 \times 4.2$  m spacing at a north-south row orientation in Fruitland, Idaho was used. Number of mixed buds on each of the four tagged branches was counted and recorded on an attached plastic tag, and branch cross sectional area was calculated on April 23, 2013.



**Figure 1.** Maximum and minum temperate fluctuations during 2013 (top) and 2014 (bottom) in Parma and Fruitland, Idaho area.

These trees were sprayed with ACC at three concentrations ( $150 \text{ mg}\cdot\text{L}^{-1}$ ,  $250 \text{ mg}\cdot\text{L}^{-1}$ , and  $350 \text{ mg}\cdot\text{L}^{-1}$ ) and Ethrel ( $300 \text{ mg}\cdot\text{L}^{-1}$ ) on May 21, 2013 when the fruitlet diameter was about 20 mm (Figure 2). Number of fruits per branch was counted on June 10, 2013. A sub-sample of 16 fruit per tree was taken on June 24, 2013 and fruit weight, diameter (D) and length (L) of each fruit were measured using a digital caliper and L/D ratio of each fruit was calculated.

2) “Sun Fuji”: In this experiment, an eight-year-old “Sun Fuji” apple orchard, where trees on Bud. 9 rootstock were planted at  $1.5 \times 3.0 \text{ m}$  spacing at a north-south row orientation in Sunny Slope, Idaho was used. Mixed buds (flower clusters) were counted on April 23, 2013. These trees were sprayed with ACC at two concentrations ( $150 \text{ mg}\cdot\text{L}^{-1}$ ,  $300 \text{ mg}\cdot\text{L}^{-1}$ ) on May 20, 2013, and fruits were counted on June 10, 2013.

3) “Top Export Fuji”: In this study, five-year-old “Top Export Fuji” apple trees on RN 29 rootstock were planted at  $1.5 \times 4.2 \text{ m}$  spacing at a north-south row



**Figure 2.** Stage of fruitlet development at the time of Ethrel and ACC sprays, when fruitlet diameter was about 20 mm in “Buckeye Gala” apple in Fruitland, Idaho on May 21, 2013.

orientation at the University of Idaho Pomology and Viticulture Orchards near Parma, Idaho. Trees in this study were sprayed with ACC at three concentrations ( $150 \text{ mg}\cdot\text{L}^{-1}$ ,  $300 \text{ mg}\cdot\text{L}^{-1}$ ,  $450 \text{ mg}\cdot\text{L}^{-1}$ ) on May 21, 2013 and fruits were counted on June 18, 2013.

## 2.6. Orchard and Treatments Descriptions in 2014

“Aztec Fuji”. For this study, a five-year old “Aztec Fuji” orchard with trees on Bud. 9 rootstock, planted at  $1 \times 3.9 \text{ m}$  spacing on a north-south row orientation at the University of Idaho Pomology and Viticulture Orchards near Parma, Idaho was used. Trees were sprayed with ACC at the rates of  $300 \text{ mg}\cdot\text{L}^{-1}$ ,  $450 \text{ mg}\cdot\text{L}^{-1}$ , and  $600 \text{ mg}\cdot\text{L}^{-1}$  when average fruit size was about 20 mm on May 13, 2014 and fruit was counted on June 14, 2014.

## 2.7. Experimental Design

The experimental design for all experiments in 2013 and 2014 was a randomized complete block with six blocks, each with six trees. The middle two trees of each segment were used for measurements. The assumption of normal data distribution was checked by computing univariate analyses for all responses in this study. Analyses of variance were conducted by General Linear Model, using SAS. Means separation was analyzed by least significant difference (LSD) at 5%.

## 3. Results and Discussion

### 3.1. “Buckeye Gala” Experiment in 2013 and Return Bloom in 2014

In 2013, application of Ethrel at  $300 \text{ mg}\cdot\text{L}^{-1}$  did not affect fruit set at hand thin-

ning time, or fruit weight, fruit diameter (D), fruit length (L), or fruit L/D ratio in the fruit sampled 34 days after applications (**Table 1**), or yield, fruit weight, color, russet, and SDP at harvest in “Buckeye Gala” apple (**Table 2**). Nevertheless, application of ACC between 150 to 350 mg·L<sup>-1</sup> had a linear dose response in fruit set and reduced fruit set by 19% to 34% (**Table 1**). Return bloom of “Buckeye Gala” in 2014 was inversely proportional to the concentrations of ACC applied in the 2013 season, so that trees receiving 350 mg·L<sup>-1</sup> had the highest return bloom and those with 150 mg·L<sup>-1</sup> had the least (**Table 1**).

“Buckeye Gala” trees of Untreated Control and those receiving Ethrel at 300 mg·L<sup>-1</sup> in 2013 had similar levels of return bloom and these levels were significantly lower than trees receiving 250 mg·L<sup>-1</sup> and 360 mg·L<sup>-1</sup> ACC in 2014 (**Table 1**). This observation suggests that contrary to other post bloom thinners that need to be applied shortly after petal fall to assure return bloom, late application of ACC effectively thins the current seasons’ fruit without adversely affecting next year’s fruit induction in “Buckeye Gala” apple.

Our fruit set results in “Buckeye Gala” apple are in general agreement with a study with ACC in “Golden Delicious” apple by Shupp *et al.* [15] who found a linear relation between rates of ACC applied at 300 - 500 mg·L<sup>-1</sup> and level of

**Table 1.** Effects of ACC on fruit set at the time of hand thinning and fruitlet size 34 days after application in 2013 and return bloom in 2014 in “Buckeye Gala” apple in Fruitland, Idaho.

Treatment	Rate	Fruit set (fruit/100 clusters)	Fruit reduction (% control)	Return bloom (No./Bcm <sup>2</sup> ) <sup>z</sup>	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Length/ diameter
Un. Control	0 mg·L <sup>-1</sup>	142 a <sup>y</sup>	0	6.64 c	29.3 c	39.0 c	36.3 c	0.935 b
Ethrel	300 mg·L <sup>-1</sup>	129 ab	9	5.78 c	29.8 c	39.2 c	36.8 bc	0.939 ab
ACC	150 mg·L <sup>-1</sup>	115 bc	19	8.67 bc	30.7 bc	39.6 bc	37.9 a	0.957 a
ACC	250 mg·L <sup>-1</sup>	96 c	32	11.14 ab	31.7 ab	40.1 ab	37.7 ab	0.941 ab
ACC	350 mg·L <sup>-1</sup>	94 c	34	12.77 a	33.0 a	40.7 a	38.3 a	0.942 ab

<sup>z</sup> 2014 return bloom = number of fruits per length of a branch, divided by the branch cross sectional area in cm<sup>2</sup> (Bcm<sup>2</sup>); Un. Control = Untreated Control. <sup>y</sup> Mean separation within columns by LSD at 5% level.

**Table 2.** Effects of ACC on yield and fruit quality attributes of “Buckeye Gala” apple at harvest in Fruitland, Idaho in 2013.

Treatment	Rate	Yield (kg/tree)	Fruit weight (g)	Fruit color (1 - 5) <sup>z</sup>	Fruit russet (%)	Fruit SDP (1 - 5) <sup>z</sup>
Un. Control	0 mg·L <sup>-1</sup>	87.1 a	110.8 b	2.67 b	4.58 a	2.70 b
Ethrel	300 μL·L <sup>-1</sup>	77.5 ab	116.6 ab	2.98 ab	3.33 a	3.10 ab
ACC	150 mg·L <sup>-1</sup>	73.1 b	116.4 ab	2.65 b	1.42 a	3.20 ab
ACC	250 mg·L <sup>-1</sup>	68.4 b	119.8 ab	3.19 ab	2.08 a	3.23 ab
ACC	350 mg·L <sup>-1</sup>	73.8 b	123.0 a	3.25 a	4.17 a	3.43 a

<sup>z</sup> Abbreviations: Fruit color rating ranged from 1 = up to 20% of fruit skin was red, progressively to 5 = the entire skin was red; SDP = starch degradation pattern, ranging from 1 = very starchy to 6 = starch mostly hydrolyzed; Un. Control = Untreated Control. <sup>y</sup> Mean separation within columns by LSD at 5% levels.

fruitlet thinning when fruitlets were at about 20 mm. Studying the effects of various rates of ACC on late post bloom thinning in apple, McArtney (2011) found a linear dose response in fruit set of individual spurs of “GoldRush” from 50 to 200 mg·L<sup>-1</sup> ACC, and reported that application of 200 mg·L<sup>-1</sup> ACC when the fruitlet diameter was at 10 mm was a useful chemical thinning treatment for apple fruit. In that study, they suggested that concentrations between 200 and 500 mg·L<sup>-1</sup> should be investigated further, focusing on the 20-mm timing. McArtney’s result in “GoldRush” apple [14] generally agrees with our results in “Buckeye Gala” apples.

Application of ACC at 250 mg·L<sup>-1</sup> or higher, increased fruit weight, diameter and length, and application of ACC at 150 mg·L<sup>-1</sup> significantly increased fruit L/D ratio as compared to Untreated Control when fruitlets were sampled 34 days after application (Table 1). Application of ACC at all rates reduced total yield per tree in “Buckeye Gala” (Table 2). Our result is in agreement with McArtney [14] who found that ACC at a rate of 200 mg·L<sup>-1</sup> to be an optimum range for late fruitlet thinning when fruitlet size was at about 10 mm in “GoldRush” apple. Our report in “Buckeye Gala” is also consistent with McArtney and Obermiller’s finding in “Gale Gala” apple [13].

Starch degradation pattern increased with every incremental increase in the ACC rate, although differences were not always significant. This effect is indirectly related to crop load, as reduced crop load on ACC-treated trees resulted in advanced maturity. Since we harvested trees of all treatments on the same day, fruit from trees thinned with ACC had advanced maturity. Even if all of the trees were hand thinned to a similar crop load, the fact that ACC reduced crop load much earlier compared to hand thinning could result in advanced fruit maturity. Application of ACC only at the rate of 350 mg·L<sup>-1</sup> significantly increased fruit size, color, and SDP as compared to Untreated Control in “Buckeye Gala” apple in 2013 (Table 2).

Based on our research, although ACC at the range of 150 to 350 mg·L<sup>-1</sup> effectively thinned “Buckeye Gala” apple, application of ACC at 350 mg·L<sup>-1</sup> provided sufficient thinning so that fruitlet size between application time and 34 days later was higher (Table 1) and fruit size at harvest (Table 2) was larger (heavier) than those from trees of Un-treated Control (Table 1 and Table 2). With an ever-increasing cost of hand thinning and labor availability challenges, application of ACC at 350 mg·L<sup>-1</sup> may be advisable for “Buckeye Gala” apple.

### 3.2. “Sun Fuji” Apple Experiment in 2013 and Return Bloom in 2014 in Sunny Slope

Application of ACC at 300 mg·L<sup>-1</sup> significantly reduced fruit set in “Sun Fuji” apple in Sunny Slope in 2013 as compared to Untreated Control (Table 3). Spray of ACC at 150 mg·L<sup>-1</sup> tended to reduce fruit set as compared to Untreated Control but the difference was not significant (Table 3). Return bloom of “Sun Fuji” apples trees receiving ACC tended to be higher than that of Untreated Control, but differences were not significant (Table 3).



**Table 3.** Effects of 1-aminocyclopropane-1-carboxylic acid (ACC) on “Sun Fuji” fruit set, yield, and fruit quality attributes at harvest at Symms Orchard, Sunny Slope, Idaho, in 2013 and return bloom in 2014.

Treatment	Rate	Fruit set (Fruit/100 clusters) <sup>z</sup>	Return bloom (buds/Bcm <sup>2</sup> ) <sup>z</sup>	Yield (kg/tree)	Weight (g)	Color (1 - 5) <sup>z</sup>	SSC (% Brix) <sup>z</sup>	Firmness (kg)	SDP (1 - 6) <sup>z</sup>	Bitter pit (%)
Un. Control	0 mg·L <sup>-1</sup>	200.2 a <sup>y</sup>	10.24 a	10.68 a	186.4 a	4.50 ab	16.6 a	8.70 a	4.32 a	13.0 a
ACC	150 mg·L <sup>-1</sup>	190.4 ab	11.82 a	10.21 a	172.3 a	4.21 b	16.1 a	8.68 a	4.07 a	21.2 a
ACC	300 mg·L <sup>-1</sup>	150.2 b	13.44 a	9.95 a	192.1 a	4.62 a	16.5 a	8.62 a	4.62 a	20.8 a

<sup>z</sup> Abbreviations: Bcm<sup>2</sup> = branch cross sectional area in cm<sup>2</sup>; return bloom was calculated as the number of half-opened mixed buds/branch cross sectional area in cm<sup>2</sup>; fruit color rating ranged from 1= up to 20% of fruit skin was red, progressively to 5 = the entire skin was red; SSC = soluble solids concentration in degree Brix; SDP = starch degradation pattern, ranging from 1 = very starchy to 6 = starch mostly hydrolyzed; Un. Control = Untreated Control. <sup>y</sup> Mean separation within columns by LSD at 5% levels.

Applications of ACC at 150 mg·L<sup>-1</sup> or 300 mg·L<sup>-1</sup> did not affect yield or quality attributes in 2013. The reason could be that trees in all treatments, including in Untreated Control, were hand-thinned to establish a 15-cm spacing, if fruits were not already at that spacing after chemical thinning.

### 3.3. “Top Export Fuji” Apple Experiment in 2013 and Return Bloom in 2014

Application of ACC reduced fruit set and increased fruit size in “Top Export Fuji”, although differences were not always significant (**Table 4**). The fruit set reduction in “Top Export Fuji” had a linear relation with the rate of applied ACC (**Table 4**). This observation is in agreement with Schupp *et al.* [15] who applied ACC at concentrations of 0, 100, 300, or 500 mg·L<sup>-1</sup> to “Golden Delicious”/ Bud.9 apple trees at 20 mm fruit diameter and found a linear dose relationship between concentration of ACC and fruit thinning.

Reduction of fruit set between trees of Untreated Control and those receiving 150 mg·L<sup>-1</sup> ACC, and between those with 300 mg·L<sup>-1</sup> and 450 mg·L<sup>-1</sup> were not significant in “Top Export Fuji” apple, but application at or greater than 300 mg·L<sup>-1</sup> ACC significantly reduced fruit set (**Table 4**). ACC applications in 2013 did not affect the return bloom of trees in 2014 in “Top Export Fuji” apple (**Table 4**), which is another excellent feature of late ACC application in “Fuji” apples.

Other than the case of fruit weight, applications of ACC did not affect yield or fruit quality attributes. The reason could be that trees in all treatments were hand-thinned at the time of hand thinning.

### 3.4. “Aztec Fuji” Apple Experiment in 2014

Application of ACC at 300 mg·L<sup>-1</sup> or greater significantly reduced fruit set in “Aztec Fuji” apple and the reduction was proportional to the dose of applied (**Table 5**).

### 3.5. General Discussion and Comments about the Study

General limitations in this study is the presence of a number of factors that could

**Table 4.** Effects of 1-aminocyclopropane-1-carboxylic acid (ACC) on fruit set, fruit yield and fruit quality attributes at harvest in “Top Export Fuji” at the University of Idaho Pomology Orchard, 2013 and return bloom in 2014.

Treatment	Rate	Fruit set (fruit/100 buds) <sup>z</sup>	Return bloom (buds/Bcm <sup>2</sup> ) <sup>z</sup>	Yield (kg/tree)	Fruit weight (g)	Water core (%)	Color (1 - 5) <sup>z</sup>	SSC (Brix) <sup>z</sup>	Firmness (kg)	Starch (SDP) <sup>z</sup>	Russet (%)
Un. Control	0 mg·L <sup>-1</sup>	199.1 a <sup>y</sup>	1.26 a	71.1 a	138.5 b	8.3 a	2.58 a	12.60 a	7.96 a	5.03 a	10.8 a
ACC	150 mg·L <sup>-1</sup>	173.4 a	4.00 a	66.7 a	166.0 a	11.1 a	2.88 a	13.37 a	8.09 a	4.89 a	14.2 a
ACC	300 mg·L <sup>-1</sup>	136.6 b	1.90 a	67.9 a	141.0 ab	19.5 a	2.46 a	12.80 a	8.07 a	5.00 a	14.2 a
ACC	450 mg·L <sup>-1</sup>	126.2 b	1.73 a	71.9 a	148.7 ab	11.1 a	2.50 a	12.60 a	7.94 a	5.71 a	12.5 a

<sup>z</sup> Abbreviations: Bcm<sup>2</sup> = branch cross sectional area in cm<sup>2</sup>; return bloom was calculated as the number of half-opened mixed buds/branch cross sectional area in cm<sup>2</sup>; fruit color rating ranged from 1 = up to 20% of fruit skin was red, progressively to 5 = the entire skin was red; SSC = soluble solids concentration in degree Brix; SDP = starch degradation pattern, ranging from 1 = very starchy to 6 = starch mostly hydrolyzed; Un. Control = Untreated Control. <sup>y</sup> Mean separation within columns by LSD at 5% levels.

**Table 5.** Effects of 1-aminocyclopropane-1-carboxylic acid (ACC) on fruit set in “Aztec Fuji” at the University of Idaho Pomology orchard, 2014.

Treatment	Rate of ACC	Fruit set (Fruit/100 buds)
Un. Control	0 mg·L <sup>-1</sup>	116.9 a <sup>z</sup>
ACC	300 mg·L <sup>-1</sup>	89.5 b
ACC	450 mg·L <sup>-1</sup>	85.9 b
ACC	600 mg·L <sup>-1</sup>	78.0 b

<sup>z</sup> Un. Control = Untreated Control. <sup>y</sup> Mean separation within columns by LSD at 5% levels.

collectively affect the success or failure of any fruit thinning practice in a given region. Stage of bloom, temperature, bee activity, varietal differences, wind, tree vigor, and spray volume are among factors influencing the effectiveness of blossom thinning in apples [4]. For post bloom thinning, stage of fruit development (size of fruit), carbohydrate reserves in the leaf, the rate of transportation of carbohydrates from leaf into fruit tissue, and all factors that contribute to the rate of this transportation such as temperature would affect strength of fruit attachment to the tree and thus impact the degree of fruitlet thinning [4]. In our study, the temperature fluctuations in both 2013 and 2014 were almost similar. Average minimum and maximum temperatures during months of April and May were 5.82°C and 21.10°C, respectively in 2013 and 5.70°C and 21.40°C, respectively in 2014 (Figure 1). We also found that ACC at the rate of 300 mg·L<sup>-1</sup> was an effective rate for post-harvest thinning in all three strains of “Fuji” (“Sun Fuji”, “Top Export Fuji” in 2013 and “Aztec Fuji” in 2014). Schupp et al. [15] reported that the impact of ACC on apple fruitlet thinning was consistent from year to year, while Jones and Koen [20] noted that the impact of Ethrel on fruit thinning varied between seasons, depending on the temperature. Relative independency of seasonal temperature effect is an outstanding feather for ACC. Modern apple growers over the past three decades have been spraying post bloom thinners when fruit let diameter is between 5 mm (shortly after petal fall)

and 10 mm. Temperatures before, during and after post-bloom applications can have major impact on apple fruit thinning. This makes application of most available post-bloom thinners risky, as growers must take a chance by applying these thinners with little or no control on weather conditions.

Application of excessively high or low rates of post bloom thinners may result in overthinning or under thinning of apples, respectively. At the same time, preexposure of fruitlets to even a moderate freeze may result in overthinning after application of a post-bloom thinner, even at an optimum rate. Also, applications of a blossom thinner or a post bloom thinner at an early stage of fruitlet development may result in serious reduction of yield if a freeze event occurs after applications of these thinners. These risks underscore the importance of ACC application which can thin fruitlet even when their diameter is about 20 mm.

Registration has been set for ACC and will be marketed as a naturally accruing compound, marketed under the brand name Accede, utilizing the active ingredient 1-aminocyclopropane-1-carboxylic acid [17].

Late application of ACC will have the following advantages to an apple grower:

- 1) The risk a freeze event is minimized at a later time in the growing season when fruit-lets are at 20 mm.
- 2) Natural fruit abortion is less, and growers will have a better idea about their final crop, and thus can make a better hand thinning strategy.
- 3) As we noticed in our study, the size of fruit in trees receiving ACC at higher rates were already larger than those of Untreated Control at about the hand-thinning time, often resulting in larger fruit size at harvest.
- 4) In general, ACC gives growers a tool to have better predictability about their final crop load and fruit quality.

#### **4. Conclusion**

Based on the results of this study, the effective range of ACC for late post bloom thinning was between 150 and 350 mg·L<sup>-1</sup> “in Buckeye Gala” and between 300 and 450 mg·L<sup>-1</sup> in different strains of “Fuji” apples. The exact optimum rate of ACC within these ranges can be decided after crop load, purpose or objective of fruit production, weather, tree vigor, and stress conditions are taken into account.

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#### **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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