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Commercial-Scale Use and Influence of 1-aminocyclopropane-1-Carboxylic Acid as a Rescue Thinner on Fruit Set and Early Fruit Growth in Apples

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Abstract

Only a limited number of post-bloom thinners is available for apple (*Malus domestica* Borkh.) at the present time. The influence of 1-aminocyclopropane-1-carboxylic acid (ACC) in two strains of 'Gala', one strain of 'Delicious', and one strain of 'Fuji' apples, when fruitlet diameter was about 20 mm, on fruit set and fruit size at hand-thinning in Southwest Idaho in the Intermountain West region, USA was studied. Applications of ACC reduced fruit set in 'Schlect Spur Delicious' in 7 and 30 days after application. Acc applications reduced fruit set in 'Gala' and 'Fuji' apples 30 days after application. Fruit weight after 30 days of ACC application (hand thinning time) in trees receiving ACC was higher than those in Untreated Control and the difference was significant only in 'Schlect Spur Delicious' apple. Application of ACC at 300 mg·L−1 or 365 mg·L−1 in this study did not have any advese effects on foliage or fruit skin in any of the tested cultivars in this project.

Keywords: Bio-regulators; Carbaryl; Crop Load Adjustment; Thinning

Introduction

Reduction of fruit set is an essential but expensive practice in commercial apple production. The influence of blossom thinners such as ammonium thiosulfate (ATS), hydrogen cyanamide (Dormex), endothalic acid (Endothal), perlargonic acid (Thinex), sulfcarbamide (Wilthin), and Tergitol TMN-6 on thinning and crop load management of apple and/or stone have been extensively tested [1,2]. However, the use of blossom thinners may increase the chance of overthinning, especially in the fruit-growing regions where spring frost frequently accrues [1,2]. Although some of these bloom thinners effectively reduce fruit sets in certain apple cultivars, other apple cultivars have shown ineffective thinning results [3,4]. Post bloom thinners such as naphthalene acetic acid (NAA), gibberelin (GA4+7), 6-benzylamino purine and 1-naphthyl-N-methylcarbamate (carbaryl) have been used for reducing fruit set in apples [5-8]. Carbaryl showed synergistic effect when used in conjunction with a commercial 6-BA formulation (MaxCel, Valent BioSciences LLC) [5,6]. 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.

Since the discovery of ethylene biosynthesis pathway [9], various studies were conducted on the regulation of ethylene biosynthesis in fruit and 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]. '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'. McArtney [14] reported that ACC reduced fruit set in 'GoldRush' apple, and the response was dose dependent. Schupp et al. [15] reported that application of ACC from 300 to 500 mg·L^{-1} to 'Golden Delicious' apple, when fruit were 20 mm, reduced fruit set.

Recently, Fallahi and McArtney [16] reported that application of ACC at the rates from 250 mg· L^{-1} to 500 mg· L^{-1}, when the

fruitlet diameter was about 17 to 20 mm, was an effective tool for late-season thinning in new apple cultivars. Valent BioSciences LLC announced registration of a new plant growth regulator, to be marketed under the brand name AccedeTM, 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 (rescue) post-bloom thinner on fruit set and early season fruit growth in a large commercial scale in various fruit-growing areas of Southwest Idaho, USA.

Materials and Methods

Description of Orchards, Treatments and Cultural Practices

Orchards for this study were located in Fruitland, Sunny Slope, and Lake Lowel regions in Southwest Idaho, USA. Trees were irrigated with a micro-jet system and trained into a tall spindle. In general, the cultural practices, other than applications of late post-bloom thinners were according to the local recommendations [18]. These practices are summarized by application of about 60 to 90 kg nitrogen/ha, calcium sprays throughout the season, and using the most environmentally sound non-organic chemicals and/or biological tools for pest, weed, and disease control [18].

The maximum and minimum temperature fluctuations in the Parma region, which is located near the fruit-growing regions of Idaho, before and during fruit thinner application and fruit set measurements (between January and July 1 were recorded during 2022 (Figure 1). All orchards were planted at a north-south row orientation and were irriagted with a drip irrigation system twice weekly to meet the evapotraspiration requirements for apple in the region. Orchards of Schlect Spur Delicious' on Bud.118 rootstock and 'Ultima Gala' on G.11 rootstock were establsied in 2017, and trees were planted at a 0.91 x 3.05 m spacing in Sunny Slope region, Idaho. Orchards of 'Ultima Gala' on RN 29 rootstock and 'Aztec Fuji' on G.935 rootstock were established in 2018 and trees were planted at a 0.91 x 3.05 m spacing in the Lake Lowel region in Southwest Idaho. An orchard of 'Foxtrot Gala'/G.41 was established in 2015, and trees were planted at 1.22 x 4.27 m spacing in 'Sunny Slope area, Idaho.

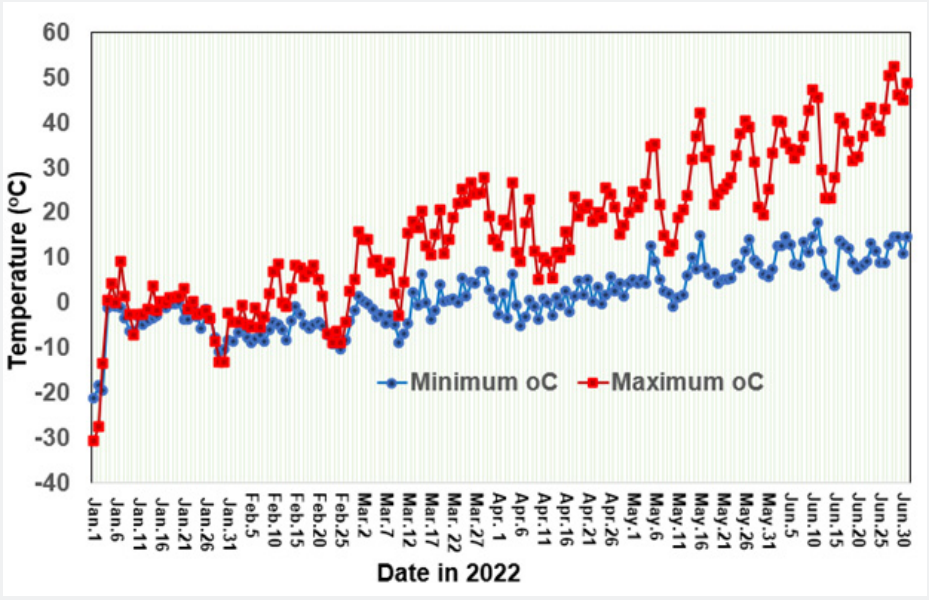

Figure 1: Maximum and minimum temperature fluctuations in the experimental orchards, early 2022.

Trees in all experimental orchards were in full bloom on around April 25, 2022 and were sprayed with lime sulfur at the rate of about 3% to 5% at 80% to 100% bloom, and carbaryl (Sevin) at post bloom. Each of these sprays was mixed with 2-butoxyethanol, poloxalene, monopropylene glycol (Regulaid; nonionic surfactant; KALO, Inc. Overland Park, KS) at 500 ul.L^{-1}. Trees in Untreated Control did not receive further thinning agent. Trees with late post bloom thinning treatments received ACC with a commercial regular airblast or tower sprayer to deliver solution at the rate of 935 L.ha-1 when the fruitlet diameter was about 17-20 mm on about June 1, 2022. Among ACC-treated cultivars, trees in the 'Foxtrot Gala' received ACC at the rate of 365 mg·L^{-1} and those in the other cultivars received ACC at the rate of 300 mg·L^{-1} in this study.

Measurements and Hand Thinning

In each orchard, trees in seven different segments were sprayed with ACC while trees in seven other semments remained

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as Untreated Control which did not receive any ACC sprays. Several trees between each Untreated Control trees and ACC-treated trees remained unsprayed as guard to prevent any possible drift or contamination on the Untreated Control trees. One tree in each of these ACC-sprayed and Untreated Control segments was randoly seleceted and tagged for various measurements. Thus, we had a randomized block design with seven sigle-tree blocks (observations) for each of the Untreated Control and ACC-sprayed treatments per orchard.

Two branches per tree, each 40- to 60-cm in length with about 0.7 to 1.3 cm diameter were selected and number of fruits in each of these tagged branches was counted about 7 days and again at the time of hand thinng which was about 30 days after ACC sprays (June 7, 2022 and June 30, 2022, respectively). At each time of counting, falling fruitlets that were in the final stages of abcssion were not counted. Fruit set was calculated as number of fruit in the tagged portion of the selected branches /number branch cross sectional area in cm^2. After fruit set measurements, fruit 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.

Experimental Design

The experimental design was a randomized block design with seven single-tree blocks (observations) per orchard. 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%.

Results and Discussion

Fruit set and Fruit Retention

Application of ACC significantly reduced fruit set in 'Schlect Spur Delicious' as early as only one week after application (Table 1). The use of ACC did not affect apple fruit set in other cultivars one week after application (Table 1). Nevertheless, ACC sprays significantly reduced fruit set in all apple cultivars 30 days after application (Table 1). This suggests that conversion of ACC to ethylene, which leads to abscission of the fruitlet and reduction of fruit set, takes place gradually and this process could be affected by several environmental factors including temperature.

Table 1: Effect of ACC on fruit set and percentage of fruit set reduction after ACC applications in different apple cultivars in 2022.

	'Schlect Spur Del.'/ Bud.118[z]		'UltimaGala'/ G.11[z]		'Ultima Gala'/ RN29		'Aztec Fuji'/ G.935[z]		'Foxtrot Gala'/ G.41[z]	
	One week	Four weeks	One week	Four weeks	One week	Four weeks	One week	Four weeks	One week	Four weeks
Un. Control	17.1 a[x]	12.3 a	21.4 a	13.3 a	31.8 a	11.7 a	22.1 a	16.6 a	33.1 a	47.7 a
ACC[y]	8.1 b	4.4 b	22.0 a	8.4 b	37.5 a	6.1 b	19.4 a	11.2 b	33.4 a	39.9 b
Reduction (%)	53	64	-	37	-	47	-	33	-	16

[z]Abbreviations: Un. Control = Untreated Control; Schlect Spur Del./ Bud.118 = Schlect Spur Delicious/ Bud.118; G. = Geneva rootstock; BCSA = Branch cross sectional area in cm^2.

[y]Acc was applied at the rate of 300 $mg{\cdot}L^{-1}$ on 'Schlect Spur Delicious'/ Bud. 118, 'UltimaGala'/ G.11, 'Ultima Gala'/RN29, and 'Aztec Fuji'/G. 935, and at the rate of 365 $mg{\cdot}L^{-1}$ on 'Foxtrot Gala'/G.41.

[x]Mean separation within columns of treatments by LSD at 5% levels.

Fruit set reduction by ACC application, as a percentage of Untreated Control, was always higher when fruit set was measured 30 days as compared to 7 days after application (Table 1). Effect of ACC on fruit set reduction in 'Schlect Spur Delicious'/ Bud.118 was faster, and effects were significant and more visible only one week after application as compared to those in other apple cultivars. The percentages of reduction in fruit set 30 days after application was 64% in 'Schlect Spur Delicious'/Bud.118, followed by 47% in 'Ultima Gala'/RN29, 37% in 'Ultima Gala'/G.11, 33% in 'Aztec Fuji'/G. 935, and 16% in 'Foxtrot Gala'/G.41 (Table 1).

Fruit set retention between seven days and 30 days after ACC application was always greater in Untreated Control trees than those receiving an ACC application (Figures 2 & 3). This observation suggests that ACC causes a higher rate of abscission in the treated trees as compared to the Untreated Control trees between application and hand thinning time. Reduction in the 'Gala' apple fruit set in this study is in general agreement with studies with ACC in 'Golden Delicious' apple by Shupp et al. [15] and in 'Gala' and 'Fuji' apples by Fallahi and McArtney [16]. They found a linear relation between rates of ACC applied from 250 or 300 $mg.L^{-1}$ to 500 $mg.L^{-1}$ and level of fruitlet thinning when fruitlets were at about 20mm. Studying the effects of various rates on ACC on late post bloom thinning in apple, McArtney [14] found a linear dose response in fruit set of individual spurs of 'GoldRush' from 50 to 200 $mg.L^{-1}$ ACC, and reported that application of 200 $mg.L^{-1}$ ACC when the fruitlet diameter was at 10 mm was a useful chemical

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thinning treatment for apple fruit. In that study, McArtney [14] suggested that concentrations between 200 and 500 mg.L^{-1} should be investigated further, focusing on the 20-mm timing.

Fruit Weight at Handthining Time

Fruit weight after 30 days of ACC application (hand thinning time) in the trees receiving ACC was higher than those in Untreated Control. However, the difference was significant only in 'Schlect Spur Delicious' apple (Table 2). This finding suggests that 'Fuji' and 'Gala' are harder to thin than 'Delicious' apples. The ability to manage crop load by ACC application will drastically reduce the cost of hand thinning, as seen in our study with 'Schlect Spur Delicious' (Figure 4) and 'Foxtrot Gala' (Figure 5).

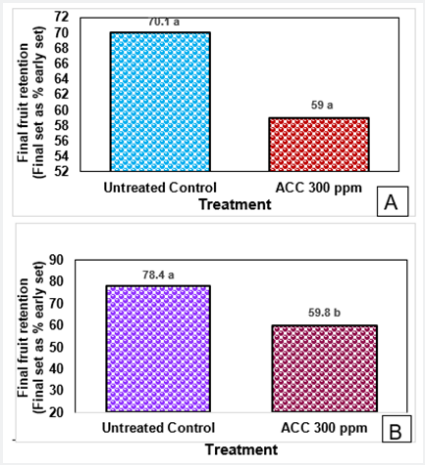

Figure 2: Effect of ACC at 300 mg·L−1 on 'Schlect Delicious/ B.118 (A) and Aztec Fuji'/G. 935 (B) final fruit retention (30 days after application, at hand thinning) as a percentage of early fruit set.

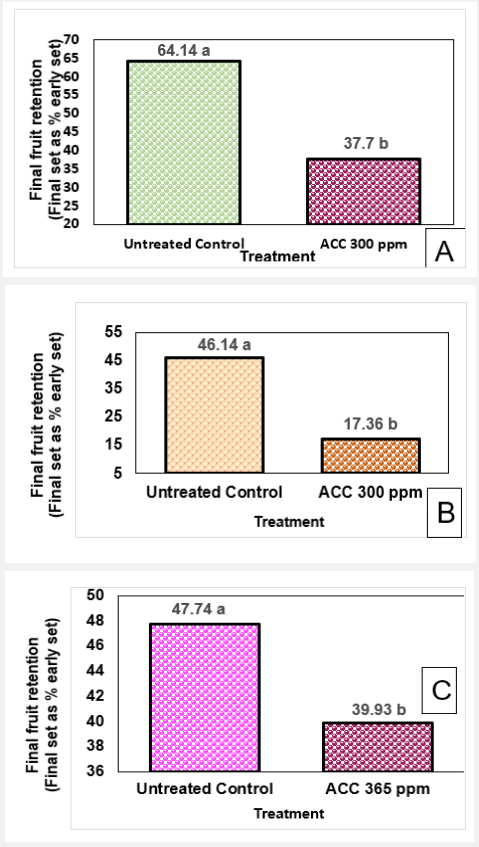

Figure 3: Effect of ACC at 300 mg·L^{-1} on 'Ultima Gala'/G.11 (A), 'Ultima Gala'/RN 29 (B), and ACC at 365 mg·L^{-1} on 'Foxtrot Gala'/ G.41 (C) apple fruitlet final fruit set retention (30 days after application) as percentage of set after 7 days of application.

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Table 2: Effect of ACC on fruit weight four weeks after applications in apples in 2022.

Treatment	Schlect Spur. Del./ B118	'Aztec Fuji'/ G. 935	'Ultima Gala'/ G.11	'Ultima Gala'/ RN29	'Fox trot Gala'/ G.41
Un. Control	30.1 b	23.1 a	29.2 a	25.8 a	22.7 a
ACC	35.1 a	26.9 a	30.9 a	25.9 a	23.8 a

[z]Abbreviations: Un. Control = Untreated Control; Schlect Spur Del./ Bud.118 = Schlect Spur Delicious/ Bud.118; G. = Geneva rootstock.

[y]Acc was applied at the rate of 300 mg·L^{-1} on 'Schlect Spur Delicious'/ Bud. 118, 'UltimaGala'/ G.11, 'Ultima Gala'/RN29, and 'Aztec Fuji'/G. 935, and at the rate of 365 mg·L^{-1} for 'Foxtrot Gala'/G.41.

[x]Mean separation within columns by LSD at 5% levels.

Figure 4: 'Schlect Delicious' in Untreated Control Trees after Hand Thinning (A) and ACC-Treated Trees before Hand Thinning (B) on June 30, 2022.

Figure 5: 'Foxtrot Gala' apples in Untreated Control Trees after Hand Thinning (A) and ACC-Treated Trees before Hand Thinning (B) on June 30, 2022.

Symptoms of Damages and Post Bloom Thinners

Some blossom and fruit thinners may have adverse effects on fruit and/or foliages. Usually the affected trees can easilty overcome these early damages on foliage as long as they are not severe. But fruit russeting and rough fruit finish on fruit skin can be a serious drawback in the apple market. Nevertheless, application of ACC at 300 mg· L^{-1} or 365 mg· L^{-1} did not have any adverse effects on foliage or fruit skin in any of the tested cultivars in this project. In this study, symptom of post bloom carbaryl application was different than those of rescue ACC application (Figure 6). Fruitlets

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that are affected by post-bloom carbaryl applications are smaller and shriveling, while the abscising fruitlets by ACC applications have darker color and are larger in size. Abscising fruitlets by ACC could be in the middle of a bunch of strong and fast-growing fruits (Figure 6).

Figure 6: Untreated Control Trees before Hand Thinning (A) and ACC-Treated Trees before Hand Thinning (B) on June 30, 2022. Abscising Fruitlets Affected by Early Carbaryl Application (small fruitlets) and late ACC application (large fruitlets) are shown on the B picture.

General Discussion and Comments

Any bloom or post loom thinning study can be affected by several environmental and genetic factors. 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 [1, 8, 16]. 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 [4,8].

In our study, the minimum and maximum temperature fluctuations seemed to have a normal pattern, showing a rise of temperatures as the growing season progressed (Figure 1). However, minimum temperatures plunged below 0°C to -2°C over several nights between April 15 and May 1, 2022, which coincided with blooming to early fruit set stages, and thus reduced fruit set in some cultivars, particularly 'Aztec Fuji'/G.935. The influence of ACC spray on fruit set and early fruit growth in 'Schlect Spur Delicious' was more evident than those in other cultivars. Currently, we don't know if and to what extent the period of freezing temperatures pre-exposed 'Schlect Spur Delicious' fruitlets to abscission. Thus, the potential impact of freezing temperatures before and after application of ACC should be studied further.

Schupp at 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 [19]. Registration has been set for ACC and is recently marketed as a naturally accruing compound, marketed under the brand name Accede, utilizing the active ingredient 1-aminocy clopropane-1-carboxylic acid [17].

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

a. The risk a freeze event is minimized later in the growing season when fruitlets are larger.

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b. 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.

c. In general, ACC gives growers a tool to better predict their final crop load.

Conclusion

Based on the results of this study, ACC at 300 or 365 mg·L^{-1} was a great late-season post bloom thinner in different apple cultivars, if this chemical was sprayed when fruitlet diameter was between 17-20 mm. Application of ACC can increase the fruitlet weight between the application and the time of hand thinning, although differences are not always significant. The objective of fruit production, weather, tree vigor, and stress conditions should be considered before applying any fruit thinner.

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