1-Aminocyclopropane Carboxylic Acid Shows Promise as a Chemical Thinner for Apple

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Abstract. The objective of these studies was to evaluate the efficacy of several concentrations of 1-aminocyclopropane carboxylic acid (ACC) for thinning apple at the standard growth stage for chemical thinning timing and a late thinning growth stage. ACC was applied at concentrations of 0, 100, 300, or 500 mg·L⁻¹ to ‘Golden Delicious’/Bud.9 apple trees at 10 mm or 20 mm fruit diameter. Treatments were applied to the point of drip to individual whole trees in a completely randomized design with five (2010) and six (2011) replications. When ACC was applied at 20 mm, there was a linear dose relationship between concentration and fruit thinning in both years. ACC was ineffective at 10 mm. The naturally occurring compound ACC shows potential for use as a reliable late chemical thinner for apple.

There is interest in developing new chemical thinners that are safe and naturally occurring. Existing thinners can cause phytotoxicity, pose hazards to beneficial and pollinating insects, and some are under review by regulatory agencies for possible withdrawal from legal use (Greene, 2002; McArtney, 2011).

Two frequently used post-bloom chemical thinners for apple, the synthetic cytokinin 6-benzyladenine and the synthetic auxin 1-naphthaleneacetic acid, produce some level of thinning over a range of timing from petal fall up to 15- to 16-mm fruit diameter (Batjer et al., 1968; Byers, 2003; Donohoe, 1968; Greene, 2002). Sometimes it may be necessary to apply thinners later than is optimal for these compounds as a result of unfavorable weather during the optimal application window, uncertainty of the strength of initial fruit set, and/or because earlier attempts to thin have failed to adequately adjust the cropload.

Currently there are two registered compounds that are effective in the late thinning window (17- to 25-mm fruit diameter): (2-chloroethyl)-phosphonic acid (ethephon) and 1-naphthyl(N)methyl carbamate (carbaryl). The ethylene-generating compound ethephon is a potent thinner that is therefore considered a risk to overthin (Greene, 2002), especially with ethephon-sensitive cultivars such as ‘Golden Delicious’ and ‘Rome’ (Byers,

2003). Carbaryl is considered a mild thinner and is most often used in a tank mix to boost the activity of other thinning chemistries. Sensitivity to chemical thinners ends when fruits reach 25 mm in diameter (Byers, 2003; Greene, 2002). It would be desirable to identify compounds with moderately strong thinning activity and a relatively low risk of excessive thinning for eventual registration and use as late thinners.

ACC is the precursor to ethylene (Adams and Yang, 1979). Several characteristics of ACC seem favorable for potential development as a plant bioregulator. ACC is a naturally occurring amino acid. The conversion of S-adenosyl methionine to ACC is the rate-limiting step in the ethylene biosynthesis pathway, and ACC is readily translocated in plants (Bradford and Yang, 1980). ACC is readily converted to ethylene by a wide variety of plant tissues (Cameron et al., 1979). Recent evidence suggests that foliar application of ACC has activity as an apple thinner (McArtney, 2011). The objective of these studies was to evaluate the efficacy of several concentrations of ACC for thinning apple at the standard growth stage for chemical thinning timing, 10-mm fruit diameter, and a late thinning growth stage of 20-mm fruit diameter.

Materials and Methods

A block of mature vertical axis ‘Golden Delicious’/Bud.9 apple trees growing at the Pennsylvania State Fruit Research and Extension Center, Biglerville, PA, at 1433 trees per hectare was selected. A factorial experiment was established with two growth stages and three concentrations of ACC with five (2010) or six (2011) replications in a completely random design. Treatments were applied on 30 Apr. or 14 May 2010 and on 11 or 20 May 2011; these dates correspond to 10- and

20-mm fruit diameters in the respective year. ACC was applied at 0, 100, 300, and 500 mg·L⁻¹ to individual trees to the point of drip using a CO₂ pressure sprayer (Bellspray, Inc., Opelousas, LA) calibrated to deliver spray at 276 KPa and fitted with a Teejet 8004 flat fan nozzle (Spraying Systems Inc., Wheaton, IL). In 2011, a spray of 300 mg·L⁻¹ ethephon [(2-chloroethyl)-phosphonic acid; Ethephon 2SL; Makhteshim-Agan of North America, Inc., Raleigh, NC] at 20 mm was included for comparison. A proprietary surfactant and buffering agent (LI-700; Crop Protection Services, Biglerville, PA) was added to all tanks at 0.12% (vol:vol) before mixing the active ingredients.

Before application, two branches per tree were selected and tagged. The number of flower clusters was counted, and at the end of June drop, persisting fruit were counted. Fruit set was extremely heavy in 2010, so after fruit set counts, the control trees were hand-thinned to a uniform crop load of seven fruits/cm² of limb cross-sectional area (LCSA). Final fruit set of unthinned trees was moderate in 2011, so the controls were not hand-thinned in that year. Fruit set was expressed as the number of fruit per LCSA. At normal commercial harvest time in September, all fruit from each tree were harvested and individually weighed by an electronic weight sizer (Durand-Wayland, Lagrange, GA). Return bloom was determined by counting the number of blossom clusters on two limbs per tree at the pink stage of flower development and calculating the number of flower clusters per LCSA.

Data were analyzed using the PROC MIXED model in SAS (SAS Institute, Cary, NC). In all cases in which there were multi-year data, significant interactions between year and timing were found. Also, in all cases, significant timing and concentration interactions were found. Therefore, we analyzed years separately in the final models and also analyzed the timings separately.

Results and Discussion

In both 2010 and 2011, ACC application at the 20-mm growth stage was effective at reducing fruit set and ineffective at 10 mm (Table 1). There was a linear dose response at 20 mm for reduction in yield and increase in fruit size. Fruit size distribution in 2010 was shifted to the larger size classes for trees treated with 300 or 500 mg·L⁻¹ at 20 mm (Fig. 1). These two treatments also increased return bloom. Fruitlet thinning response at 20 mm from ACC at 500 mg·L⁻¹ was similar to that of 300 mg·L⁻¹ ethephon (data not presented). This comparison was made because ‘Golden Delicious’ is easily overthinned with ethephon (Byers, 2003). It appears that there is a gradual dose response to ACC for this important cultivar that would facilitate a range of thinning options for the practitioner.

In 2011 application of ACC at both growth stages produced similar thinning dose responses to those in 2010, resulting in reduced yield with increasing ACC concentration

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Table 1. Treatment means with application of 1-aminocyclopropane carboxylic acid concentration at two growth stages (10-mm size and 20-mm size) of fruit set, cropload, yield, yield efficiency, fruit size, and large fruit fraction of 'Golden Delicious' during the 2010 and 2011 growing seasons.^z

Concn (ppm)	2010		2011	
	10 mm	20 mm	10 mm	20 mm
-----Fruit set (no./LCSA)-----				
0	15.8	—	11.7	—
100	17.4	11.6	9.3	14.2
300	13.1	10.6	8.1	7.6
500	16.6	4.2	9.8	4.6
Significance				
Linear	NS	0.0001	NS	0.0003
Quadratic	NS	NS	NS	NS
-----Yield (kg/tree)-----				
0	42.5	—	42.3	—
100	45.6	42.5	34.1	38.9
300	49.9	34.9	24.5	22.2
500	42.0	24.5	28.9	24.8
Significance				
Linear	NS	0.0001	0.0077	0.0109
Quadratic	NS	NS	0.0354	0.0343
-----Fruit size (g)-----				
0	127.3	—	161.9	—
100	127.1	126.7	189.3	171.9
300	129.5	170.4	196.6	194.7
500	122.1	179.6	181.5	208.2
Significance				
Linear	NS	0.0109	0.0010	0.0013
Quadratic	NS	0.0343	0.0024	NS
-----Cropload (no./TCSA) ^y -----				
0	—	—	9.07	—
100	—	—	6.38	7.12
300	—	—	4.46	3.72
500	—	—	6.14	2.10
Significance				
Linear	—	—	0.0005	0.0185
Quadratic	—	—	0.0025	NS
-----Yield efficiency (kg/TCSA) ^y -----				
0	—	—	1.46	—
100	—	—	1.20	1.21
300	—	—	0.86	0.72
500	—	—	1.11	0.45
Significance				
Linear	—	—	0.0108	0.0004
Quadratic	—	—	0.0302	NS
-----Large fruit fraction (% of total yield greater than 76 mm)-----				
0	10.6	—	36.4	—
100	8.7	8.6	63.4	46.8
300	7.8	38.1	71.2	69.9
500	6.2	53.3	58.7	82.2
Significance				
Linear	NS	0.0001	0.0003	0.0005
Quadratic	NS	NS	0.0012	NS
-----Return bloom (no. clusters/LCSA)-----				
0	6.23	—	12.4	—
100	6.40	5.55	12.1	9.27
300	7.49	17.7	16.1	20.9
500	5.65	19.1	17.1	20.8
Significance				
Linear	NS	0.0010	0.0373	0.0002
Quadratic	NS	NS	NS	NS

^zTreatment means of five (2010) or six (2011) replicates.

^yMeasurements of cropload and yield efficiency were not made in 2010.

LCSA = limb cross-sectional area; NS = nonsignificant; TCSA = trunk cross-sectional area.

when applied at 20 mm (Table 1). Application of ACC at 20 mm resulted in a strong and very highly significant negative relationship between ACC concentration and crop density. Although blossom cluster counts show

that the potential crop was supraoptimal in 2011 (an overall average 16 clusters/cm² LCSA with all plot averages above 14 clusters/cm² LCSA), the cropload after June drop on untreated control trees was nearly optimal,

suggesting that a carbon deficit caused by environmental factors alone was adequate to adjust cropload in this orchard in 2011 (Lakso et al., 2001). Consequently, any additional thinning resulting from effective treatments reduced fruit set below the optimal level. Although increasing concentrations of ACC at 20 mm increased the proportion of large fruit (Fig. 1), because ACC at either timing reduced crop below the optimal cropload, there was only a small gain in the yield of large fruit to compensate for the loss of total yield in 2011.

Daily light and temperature data were used for calculation of the MaluSim carbon balance model (Lakso et al., 2001), which showed a period of carbohydrate surplus immediately after the 10-mm application in 2010 and a period of moderate stress after the 20-mm application (Fig. 2). MaluSim calculations showed several periods of strong carbon balance deficit in 2011, resulting from high temperatures and low light conditions during the natural fruit set period. One of these stress periods coincided with the 10-mm treatment. A severe deficit also occurred shortly after the 20-mm treatment was applied.

No symptoms of phytotoxicity were observed in either year (data not presented). McCartney (2011) observed some yellowing of 'GoldRush' leaves in 1 of 2 years when dilute application was made to individual spurs with a spray bottle but not when sprays were applied to 'Pink Lady' trees by airblast sprayer. Additional study is needed to determine if certain cultivars are more sensitive, what the maximum safe concentration is for such cultivars, and to optimize spray application technology for ACC.

ACC had efficacy at 20 mm in both years of our study. McCartney (2011) reported that although 'Pink Lady' trees had no thinning response to ACC, there was elevated ethylene generated in detached spurs by 10 mm and earlier treatments, but ethylene evolution was muted when ACC was applied at 20 mm. Ethephon is effective as a blossom thinner (Jones, 1990) but is ineffective 7 d after bloom (Bound et al., 1993). Etephon efficacy as a post-bloom thinner redevelops as fruits reach 16 mm in diameter (Marini, 1996). Our data from both years show a similar relationship between fruit growth stage and sensitivity to ACC.

The dose response at 20-mm fruit diameter was strong and linear in both years. This suggests that there may be a considerable range of appropriate rates of ACC for apple thinning. If true, this would allow concentration adjustments to year-to-year variations in fruit set and to the weather forecast at the time of application. The apparent wide range in ACC dose response is especially noteworthy because 'Golden Delicious' is highly sensitive to ethephon, which restricts the commercial application of ethephon to a low rate on this cultivar (Byers, 2003). McCartney (2011) also noted a linear dose response in fruit set of individual spurs of 'GoldRush' from 50 to 200 mg·L⁻¹ ACC,

Fig. 1. Fruit size distribution of 'Golden Delicious' sprayed with three concentrations of 1-aminocyclopropane carboxylic acid at the 20-mm fruit diameter growth stage.

Fig. 2. MaluSim carbon balance model for 2010 and 2011 thinning seasons, Biglerville, PA. Crosses indicate dates of application of 1-aminocyclopropane carboxylic acid at 10-mm and 20-mm fruit growth stages, respectively.

although whole tree sprays of ACC to 'Pink Lady' were ineffective at full bloom, 10 mm, or 20 mm. ACC was consistently effective when used at 300 or 500 mg·L⁻¹ in our studies at the 20-mm timing. Our results, taken in

consideration with those of McArtney (2011), suggest that concentrations between 200 and 500 mg·L⁻¹ should be investigated further, focusing on the 20-mm timing, and that trials should be conducted to compare

cultivar sensitivity to ACC. The observed rate responses to ACC concentration occurred both years under hot temperatures, a condition under which overthinning with ethephon has been observed (Jones and Koen, 1985).

Our studies show that ACC has potential for development as an effective late chemical thinner for apple.

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