Ethenoph with 1-Aminocyclopropane-1-Carboxylic Acid Can Defoliate Grapevines, and Thereby Improve Vine-drying of Grapes

Thiago Vieira da Costa¹, João Alexio Scarpare Filho¹, and Matthew W. Fidelibus²,³

SUMMARY. In two experiments, various combinations of ethephon, with or without 1-aminocyclopropane carboxylic acid (ACC), were applied to the fruiting zone of ‘Selma Pete’ raisin grapes (Vitis vinifera) to determine whether any could serve as a defoliant, and if so, whether defoliation improved subsequent vine drying of the grapes. In the first experiment, the fruiting zone was treated on 8 Aug. 2013 with a control (water) and one of four plant growth regulator (PGR) treatments: 1000 ppm ethephon, 1000 ppm ethephon plus 1000 ppm ACC, 2000 ppm ethephon, and 2000 ppm ethephon plus 1000 ppm ACC. In the first experiment, treatment with any of the PGRs hastened leaf senescence, but leaf greenness, measured with a SPAD meter, declined most rapidly in leaves from vines treated with 2000 ppm ethephon or 2000 ppm ethephon plus 1000 ppm ACC, and defoliation was best in vines treated with 2000 ppm ethephon plus 1000 ppm ACC. None of the treatments in the first study affected berry composition, hastened berry drying, or ultimately affected raisin moisture or quality. In a second experiment, initiated 18 days later, a factorial design was employed to determine whether three chemical treatments, a control (water spray), 2000 ppm ethephon, and 2000 ppm ethephon plus 1000 ppm ACC, might interact with fruiting zone orientation (east or west facing) to affect leaf senescence or berry drying. The second study confirmed that 2000 ppm ethephon and 2000 ppm ethephon plus 1000 ppm ACC induced rapid leaf senescence. Defoliation proceeded more rapidly in the second study and by 13 days after treatment, vines treated with 2000 ppm ethephon plus 1000 ppm ACC had less than one leaf layer remaining in the fruiting zone compared with more than 2.5 leaf layers in untreated vines. Treatments again had no effect on berry fresh weight or composition, but grapes on west-facing vines treated with 2000 ppm ethephon plus 1000 ppm ACC dried significantly better than grapes on vines subjected to other treatments, possibly because the higher temperatures of west-facing vines coupled with better defoliation of the 2000 ppm ethephon plus 1000 ppm ACC treatment was sufficient to improve grape drying compared with vines subjected to other trellis orientation and chemical treatment combinations. Therefore, we conclude that treatment with ethylene-promoting PGRs can defoliate the fruiting zone of ‘Selma Pete’ grapes with divided canopies, and such defoliation treatments may enhance berry drying when drying is initiated later than normal.

CALIFORNIA’s San Joaquin Valley has been a global leader in raisin production for more than a century (Fidelibus, 2014). Most of California’s raisins are made from ‘Thompson Seedless’ grapes (Vitis vinifera) that are hand harvested onto paper trays and left in the vineyard to dry. However, technological advances and economic and social changes increasingly favor adoption of mechanized production methods such as dry-on-vine (DOV) (Fidelibus, 2014). In DOV vineyards, grapevine canes bearing mature fruit are severed to initiate drying, and the grapes are left on the trellises to DOV (May and Kerridge, 1967). Grapes DOV more slowly than they dry on trays because temperatures in the canopy are lower than those at the soil surface (Christensen and Peacock, 2000). The slow drying rate is one disadvantage of the DOV method; raisins that have not dried to <16% moisture by mid-October, which is generally considered to be the end of California’s drying season, may have to be finish dried, increasing production costs (Fidelibus et al., 2007). In Australia, an alkaline drying emulsion is used to hasten drying and to help preserve the light color typical of Sultana raisins (Clingleefer, 2011; Grnacarevic and Lewis, 1976). However, drying emulsion is not widely used in California because a dark-colored “natural” raisin is preferred. Thus, in California, the risk of inadequate drying is primarily managed by initiating cane severance as soon as fruit have amassed ≥ 20% soluble solids (Parpinello et al., 2012).

Raisin grapes that ripen earlier than ‘Thompson Seedless’, such as ‘Selma Pete’, have been selected for DOV (Fidelibus et al., 2008). Prompt cane severance of early-ripening varieties greatly increases the likelihood of adequate drying (Parpinello et al., 2012), but additional measures may be beneficial in years when grapes ripen later than normal, or when atypically cool or wet weather occurs during the normal drying period. Drying should be hastened by canopy management practices that increase fruit exposure to the sun. Practices such as separating fruit-bearing canes from sterile renewal shoots and defoliation of the fruiting zone have been suggested as possible ways to improve fruit drying (Fidelibus et al., 2007; Peacock and Swanson, 2005). Separating the canopy may prevent leaves on renewal shoots from shading fruit, and defoliating shoots on fruiting canes should further expose

Additional Index Words. ACC, dry-on-vine, DOV, Vitis vinifera, leaf abscission, raisin

This research was made possible by financial support from São Paulo Research Foundation (FAPESP).

We thank Valent BioSciences for providing 1-aminocyclopropane-1-carboxylic acid, and Shijian Zhuang and Lindsay Jordan, University of California Cooperative Extension, for reviewing an earlier draft of this manuscript.

¹Department of Horticulture, University of São Paulo, Piracicaba, SP, 13418-900, Brazil
²Department of Viticulture and Enology, University of California, Davis, CA 95616
³Corresponding author. E-mail: mwfidelibus@ucdavis.edu.

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³Corresponding author. E-mail: mwfidelibus@ucdavis.edu.

To convert U.S. to SI, multiply by

| Units          | To convert SI to U.S., multiply by |
|----------------|-----------------------------------|
|                | U.S. unit | SI unit |                      |
| 10             | %         | g L⁻¹   | 0.1                   |
| 0.3048         | ft         | m       | 3.2808                |
| 3.7854         | gal        | L       | 0.2642                |
| 0.4536         | lb         | kg      | 2.2046                |
| 28.3495        | oz         | g       | 0.0353                |
| 1              | ppm        | mg L⁻¹  | 1                     |
| (°F – 32) + 1.8| °F         | °C      | (°C × 1.8) + 32       |

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clusters of fruit to the sun since most leaves on severed canes do not abscise, even after they become desiccated. Fidelibus et al. (2007) observed that canopy separation and defoliation methods interacted with each other and with drying conditions to affect drying of ‘Thompson Seedless’ grapes on traditional trellises. For example, burning or blowing dead leaves from the vines only improved berry drying on vines with divided canopies in a year with poor drying conditions, and not in two other years with better conditions (Fidelibus et al., 2007). Moreover, leaf blowing sometimes increased moldiness of dried fruit, and a grower reported that burning did the same, apparently because these defoliation methods may damage drying fruit (Fidelibus et al., 2007).

The PGR ethephon was also tested as a potential defoliant for ‘Thompson Seedless’, but the highest concentration tested, 750 ppm, had no obvious effect on fruit or foliage (Fidelibus et al., 2007). However, higher rates of ethephon have been shown to be an effective postharvest defoliant of grapevines in tropical areas (Fracaro and Boliani, 2001), suggesting that ethylene-promoting PGRs can defoliate grapevines if sufficiently high concentrations are used. Application of ACC, a naturally occurring biochemical precursor of ethylene, with ethephon might improve efficacy or enable the use of lower rates. To our knowledge, ACC has not been tested as a defoliant of grapevines, but ethephon and ACC were found to have similar effects on olive fruit abscission (Burns et al., 2008).

Regardless of how vines are defoliated, it is important that only fruit-bearing shoots from canes, the leaves on which account for ≈50% of vine canopy (Scholefield et al., 1977), are defoliated. Shoots on canes are killed by cane severance anyway, and vines can annually sustain such damage with minimal effects on future productivity (Scholefield et al., 1977). However, additional defoliation (i.e., >50%) can reduce vine vigor and yield in subsequent seasons (Scholefield et al., 1977). Therefore, defoliants should be applied in a manner that maximizes coverage of fruiting zone foliage, to optimize efficacy, and minimizes contact with non-target foliage or fruit. The Shaw swingarm trellis (Shaw, 2000) has design features that could be ideal for such an application. The canopy can be clearly divided into fruiting and renewal zones by tying fruiting canes to the lower half of the sloping T-shaped cross arm and directing renewal shoots toward the upper half, allowing sprays to be restricted to the fruiting zone. Further, clusters of mature fruit hang below the foliage, so a PGR spray from above the canopy could achieve excellent coverage of leaves, which would somewhat shield fruit from direct spray contact. The primary objectives of this research were to determine whether ethylene-promoting PGRs might have potential to defoliate fruiting shoots of ‘Selma Pete’ and, if so, whether defoliation improved DOV of ‘Selma Pete’ raisin grapes on a Shaw swingarm trellis.

Materials and methods

In 2013, two studies were conducted on ‘Selma Pete’ grapevines grafted to ‘Harmony’ [V. champinii × (V. solonis × V. othello)] rootstocks, at the University of California Kearney Agricultural Center, Parlier, CA (lat. 36.598°N, long. 119.503°W, 344-ft elevation). Vines were planted in 2000 at a 6.5 × 11.5-ft spacing (within and between rows, respectively) trained to bilateral cordons, and supported by a Shaw swingarm trellis (Shaw, 2000) in rows oriented north to south. The 3-ft-long bilateral cordons were supported by a wire attached at 5.5 ft aboveground level to 6-ft-tall vertical steel stakes. At this height, the cordon wire nearly bisects a 9-ft-long crossarm that is also attached to the stake at a point just below the cordon wire. Each crossarm is bolted to a stake at its midpoint, and braces are used to fix the arms at a 50° angle. The crossarms support four parallel wires, two above the cordon wire and two below, each spaced 1.28 and 2.45 ft from the center of the arm. Fruiting canes are tied to the wires below the cordon wire and, in spring, a movable rake wire attached to the tip of masts on each stake is pivoted toward the top of the trellis to guide renewal shoots away from the fruiting section. Arms on adjacent rows are inclined in opposite directions (i.e., east or west facing on north-south rows) to help ensure even raisin drying across the vineyard. In Winter 2013, all vines were pruned to six 15-node canes, and canes were tied to two foliage wires below the cordon wires. Trellis design features and cane arrangement are shown in Fig. 1.

The first experiment was initiated on 8 Aug. 2013. Pairs of adjacent vines were assigned to receive one of the following treatment solutions: control...
again 9 and 14 d after application to monitor defoliation. The measurements were made by passing a sharp steel rod through the canopy at 20 points, each 4 inches along a horizontal transect in the middle of the fruit zone of each plot. The number of leaf and cluster layers was calculated by dividing the number of contacts with leaves or clusters by the number of passes. Canopy leaf temperature was measured daily for 14 d with a handheld infrared (IR) thermometer (model 39650-04; Cole-Parmer, Chicago, IL).

Infrared thermometer measurements were made by directing the instrument at the exterior of the treated canopy surface at 1300 HR, using an average of three measurements per plot. Ambient temperatures throughout the study periods were recorded by an onsite weather station (KAC), and downloaded from an internet database (California Weather Data, 2015)

Fruiting canes on vines in each plot were severed 14 d after chemical treatments were applied to initiate fruit drying. By 26 Sept., grapes in
Table 2. Number of clusters, cluster abscission, raisin yield, moisture content, and “B and Better” and “Substandard” grades from ‘Selma Pete’ grapevines subjected to ethephon and 1-aminocyclopropane-1-carboxylic acid (ACC) sprays on 8 Aug. and harvested on 26 Sept. 2013 in Parlier, CA.

| Treatment* | Clusters (no./vine) | Cluster abscission (%) | Yield (kg/vine)* | Moisture (%) | Quality (% B and Better) | Substandard (%) |
|------------|---------------------|------------------------|-----------------|-------------|-------------------------|----------------|
| Control    | 58.83 ab            | 0.50 ab                | 6.85            | 13.16 ab    | 84.17                   | 4.75           |
| 1000 ppm ethephon | 53.16 b            | 0.33 b                | 5.64            | 12.75       | 80.75                   | 4.02           |
| 1000 ppm ethephon + 1000 ACC | 59.66 a            | 0.66 ab               | 7.15            | 13.50       | 86.89                   | 4.43           |
| 2000 ppm ethephon | 54.66 a            | 0.66 ab               | 5.70            | 13.58       | 76.81                   | 6.52           |
| 2000 ppm ethephon + 1000 ACC | 58.66 a            | 1.33 a                | 6.83            | 13.25       | 78.94                   | 4.65           |

*1 ppm = 1 mg L⁻¹, 1 kg = 2.2046 lb.
Values are treatment means (n = 6). Mean followed with no letter suggest no difference, according to Tukey’s test (P < 0.05).
before they had fully dried because favorable drying weather was no longer forecast and further environmental exposure was likely to result in spoilage. Therefore, partially dried grapes were harvested as in the first study. Some of these grapes were too moist to use a dried fruit moisture meter, so a subsample of raisins was weighed, put in a forced air oven (model T35HV; Gruenberg Oven, Williamsport, PA) at 60 °C, and dried to a constant weight. Moisture content was then determined gravimetrically using a balance (model FG-60KAM; A&D Co., Tokyo, Japan). A second sample of partially dried grapes from each plot was also placed in a forced air oven, but only until fruit appeared to dry to between 9% and 16% moisture, the range of moisture content needed to make valid quality measurements with an air stream sorter. Moisture content of each grape sample was confirmed with a dried fruit moisture meter, and their quality grades were determined with air stream sorter analyses (Fisher et al., 1961).

Data analyses for both trials were performed using SAS (version 9.2; SAS Institute, Cary, NC) and SigmaPlot (version 10; Systat Software, San Jose, CA). Results were tested for homogeneity of variance and subjected to analysis of variance. Means were compared by Tukey’s test (P < 0.05).

Results and discussion

First study. Untreated control leaves exhibited a gradual linear decline in SPAD values across the 2-week period between spray application and cane severance (Fig. 2). In contrast, SPAD values of leaves treated with 1000 ppm ethephon declined more rapidly, though also in a linear fashion. Leaves of vines treated with 1000 ppm ethephon plus 1000 ppm ACC or 2000 ppm ethephon responded with a similar quadratic reduction in SPAD values, suggesting ACC may have a similar potency as ethephon, at least when coapplied, as was the case in this study. Treatment with 2000 ppm ethephon plus 1000 ppm ACC also resulted in a quadratic reduction in SPAD values, but values declined at a more rapid rate compared with other treatments. Defoliation proceeded more slowly than the decline in SPAD values, and treatments did not affect leaf layer numbers until 14 d after treatment (DAT) (Table 1). By then, vines treated with 2000 ppm ethephon, or 2000 ppm ethephon plus 1000 ppm ACC had fewer leaf layers than vines subjected to other treatments (Table 1). Leaves on renewal shoots retained a normal appearance and did not abscise, regardless of treatment (personal observation).

Before treatment, berry weights ranged from 1.61 to 1.71 g/berry, soluble solids averaged about 23%, and titratable acidity ranged from 5.4 to 5.8 g/L. By 14 DAT, average berry weight declined slightly to between 1.53 and 1.68 g/berry, and soluble solids increased to 24.5% to 26.75%, titratable acidity remained about the same as before, and no treatments affected berry mass or composition (data not shown). The slight decrease in berry weight and increase in soluble solids suggest berries were slowly desiccating, although canes had not yet been severed (cane severance immediately followed the 14 DAT sample collection). This is consistent with previous observations that the berries of some DOV varieties, including ‘Selma Pete’, have a tendency to desiccate after ripening (Aung et al., 2002; Fidelibus, 2014). Ethephon may be used to hasten ripening of raisin grapes (Szyjewicz et al., 1984); the fact that none of the treatments increased soluble solids in this trial is likely because fruit already had amassed a high level of soluble solids at treatment and thus may have already been fully ripe.

Table 3. Leaf layers in ‘Selma Pete’ grapevines, subjected to ethephon and 1-aminoacyclopropane-1-carboxylic acid (ACC) sprays on 0, 7, and 13 d after treatment (26 Aug. 2013) in Parlier, CA.

| Treatment                                      | Leaf layers (no.) |
|-----------------------------------------------|-------------------|
|                                               | Days after treatment |
|                                               | 0     | 7     | 13    |
| Control                                       | 2.87a  | 2.46 b | 2.65 c |
| 2000 ppm ethephon                            | 2.61   | 2.06 b | 2.05 b |
| 2000 ppm ethephon + 1000 ppm ACC              | 2.85   | 1.28 a | 0.87 a |

*1 ppm = 1 mg L⁻¹.

Values are treatment means (n = 4). Means followed by a different letter, within columns, are significantly different according to Tukey’s test (P < 0.05).

Fig. 4. Minimum, average, and maximum daily ambient temperatures at the Kearney Agricultural Center, Parlier, CA, during the course of the experiments, 8 Aug. (day of year 220) through 21 Oct. (day of year 294); (1.8 × °C) + 32 = °F.
After ≈40 DAT, abscised clusters were observed in some plots. The 2000 ppm ethephon plus 1000 ppm ACC treatment induced more cluster abscission than other treatments, but not enough to influence the average number of clusters retained per vine or raisin yield at harvest (Table 2). Raisins were harvested from these plots in September, and moisture content and quality were acceptable and unaffected by treatments (Table 2). Both findings are understandable, as drying conditions during the first study were excellent (Fig. 3), and treatments did not affect soluble solids levels, a variable which has a dominating influence on raisin quality (Parpinello et al., 2012). In 2014, the season following treatment, shoot emergence began on 27 Feb. 2014, reaching 70% by 5 Mar. 2014. None of the treatments affected the rate of percent budbreak, or overall percent budbreak.

**Second Study.** The 2000 ppm ethephon and 2000 ppm ethephon plus 1000 ppm ACC treatments induced a rapid decline in SPAD values (Fig. 3), confirming the findings of our previous study. After 14 d, fruiting zone leaves on vines treated with 2000 ppm ethephon had 19.5% lower SPAD values than those of leaves on untreated vines, and vines treated with 2000 ppm ethephon plus 1000 ppm ACC had SPAD values that were 56.2% lower than those of untreated vines. These findings are similar to those in the previous study where identical treatments reduced SPAD values by 26% an 65%, respectively. Defoliation proceeded more rapidly than in the previous study, and treatment effects were noted on 7 and 13 DAT. By 13 DAT, vines treated with 2000 ppm ethephon and 1000 ppm ACC had less than one leaf layer in the fruiting zone compared with more than 2.5 leaf layers in untreated vines (Table 3). Better defoliation observed in the second study may be because leaves were slightly older. Older leaves generally have lower auxin levels in the abscission zone, which makes them more sensitive to ethylene action (Beyer, 1975).

Treatments had no effect on berry weight, soluble solids, or titratable acidity, before or after the treatment, as observed in the previous study. Berry weight, soluble solids, and titratable acidity ranged from 1.64 to 1.70 g, 26.7% to 27.9%, and 5.3 to 6.3 g L⁻¹, respectively, before treatments, and 1.58 g, 26.6%, and 3.9 g L⁻¹, respectively, on 14 DAT. These data also suggest berries desiccated slightly during the observation period before cutting the canes.

Because of later cane severance date of the second study, daylengths and temperatures were declining (Fig. 4), and grapes did not dry as well as they did in the first study. Slow drying and forecasted poor drying conditions made it necessary to harvest the grapes before most of them had dried to below the maximum allowable moisture content of 16% (Table 4). Treatment effects on grape drying depended on grapevine canopy orientation. Treatments did not affect grape moisture contents on vines with east-facing canopies, but treatment with 2000 ppm ethephon plus 1000 ppm ACC significantly improved drying of grapes on vines with west-facing canopies (Table 4). The fruiting zone of west-facing vines experienced greater peak temperatures than the fruiting zone of east-facing vines (Fig. 5), which were facing away from the sun during the hottest part of the day, in agreement with others (Spayd et al., 2002), who showed that clusters of grapes exposed to the west may attain much greater afternoon temperatures than clusters exposed to the east. Evidently, higher temperatures of west-facing vines coupled with the better defoliation of the 2000 ppm ethephon plus

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**Table 4. Effect of plant growth regulator treatments and trellis orientation on moisture content of ‘Selma Pete’ grapevines in Parlier, CA.**

| Treatment                      | Moisture (%)  |
|-------------------------------|---------------|
|                               | East | West  |
| Control                       | 17.00⁷   | 21.67 a |
| 2000 ppm ethephon             | 19.67   | 18.33 a |
| 2000 ppm ethephon + 1000 ppm ACC | 15.67  | 12.00 b |

⁷1 ppm = 1 mg L⁻¹.

⁸Values are treatment means (n = 4). Means followed by a different letter, within columns, are significantly different according to Tukey’s test (P < 0.05).

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**Fig. 5. Average temperature from ‘Selma Pete’ grapevine canopy surface in the middle of the fruit zone of each plot on vines oriented west or east, in north-south rows 29 Aug. 2013 in Parlier, CA; (1.8 × °C) + 32 = °F.**
1000 ppm ACC treatment was sufficient to improve grape drying compared with vines subjected to trellis orientation and chemical treatment combinations.

Some cluster abscission was once again observed beneath vines treated with 2000 ppm ethephon plus 1000 ppm ACC, but as in the first study, yield was unaffected (Table 5). Raisin quality was unaffected by row orientation, chemical treatment, or their interaction (data not shown). Pruning weights, rate of budbreak progression, and total overall budbreak in Spring 2014 were also unaffected by any of the treatment combinations (data not shown).

**Conclusions**

Treatments with ethylene plus ACC-promoting PGRs can selectively defoliate the fruiting zone of ‘Selma Pete’ grapes with divided canopies, and such defoliation treatments may enhance berry drying.

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**Table 5. Number of clusters per vine, cluster abscission and yield of ‘Selma Pete’ grapevines subjected to ethephon and 1-aminocyclopropane-1-carboxylic acid (ACC) sprays in Parlier, CA.**

| Treatment* | Clusters (no./vine) | Cluster abscission (%) | Yield (kg/vine)* |
|-----------|---------------------|-----------------------|-----------------|
| Control   | 65.67†              | 0.17                  | 6.40            |
| 2000 ppm ethephon | 57.00               | 0.83                  | 5.34            |
| 2000 ppm ethephon + 1000 ppm ACC | 57.17               | 2.33                  | 5.79            |

*1 ppm = 1 mg L⁻¹, 1 kg = 2.2046 lb.

†Values are treatment means (n = 4). Mean followed with no letter suggest no difference, according to Tukey’s test (P < 0.05).