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Effect of Water Conditioners and Surfactants on Vegetative Growth Control and Fruit Cracking of 'Empire' Apple Caused by Prohexadione-calcium

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Abstract. **Three experiments were conducted on 'Empire' apple (*Malus ×domestica* Borkh.) to evaluate the effects of hard water, calcium chloride ($CaCl_2$), water conditioners, surfactants, and captan fungicide on the growth reduction and fruit cracking caused by prohexadione-calcium (PC). Two applications of 63 mg·L^{-1} PC provided season-long growth control in two studies. Adding a water conditioner to PC reduced shoot growth more than an application of PC in hard or soft water in one New York study. Ammonium sulfate (AMS) and Choice were equally effective water conditioners. PC provided no growth control of water sprouts and had no effect on fruit set or yield. PC applied at 250 mg·L^{-1} reduced fruit size. 'Empire' fruit cracking and corking was severe, despite the use of only 63 mg·L^{-1} PC in two of the three experiments. This damage was exacerbated by the addition of a water conditioner, however AMS applied with a surfactant but without PC had little or no effect on either the severity or extent of fruit injury. In a third experiment, the addition of surfactants, $CaCl_2$, or captan to 250 mg·L^{-1} PC plus a water conditioner had no effect on the severity of fruit damage. Fruit cracking caused by PC increased preharvest drop in two of three experiments, and increased postharvest rot in the Geneva, N.Y., experiment where fruit were stored prior to grading. Application of PC plus a water conditioner reduced estimated gross return per hectare for 'Empire'. We conclude that the fruit injury is caused by the formulated PC product itself under certain environmental conditions, and that this product should not be used on 'Empire'. Chemical name used: calcium 3-oxido-4-proprionyl-5-oxo-3-cyclohexine-carboxylate [prohexadione-calcium (PC)].**

Prohexadione calcium [(PC), trade name Apogee, BASF Corp., Research Triangle Park, N.C.] is a growth retardant recently registered for use on apples. PC reduces the synthesis of gibberellins (GA) by inhibition of C-3 hydroxylation of GA_{20} to GA_1, resulting in reduced cell elongation (Evans et al., 1999).

PC can cause fruit corking and cracking when applied to the apple (*Malus ×domestica* Borkh.) cultivar Empire. This injury is sporadic, and the circumstances that lead to expression of the injury are not known. Injury has occurred across several years in Michigan, New York, Ohio, and Pennsylvania (Gar Thomas, personal communication). 'Empire' is the only cultivar thus far identified as having fruit that are susceptible to damage by PC. The sporadic nature of the fruit damage to 'Empire' following PC application suggests that one or more environmental or application factors may be contributing to this problem. Since PC is applied as a foliar spray, the presence of other agricultural chemicals applied to fruit may be involved in 'Empire' corking and cracking.

The Apogee label states that its efficacy is reduced if the source of spray water is high in calcium carbonate ("hard water"), or if calcium-containing fertilizers are added to the spray solution. The formulated product, Apogee, contains ammonium sulfate for this reason (Gar Thomas, personal communication). Applicators are advised to add one pound of AMS as a water conditioner for every pound of Apogee when mixing spray solutions from a hard water source, however the degree of hardness at which PC efficacy is reduced is not known. Foliar applications of nitrogen fertilizer salts can cause phytotoxicity when applied at excessive concentrations, under poor drying conditions, or when applied with pesticides (Stiles and Reid, 1991). In large scale, unreplicated trials, 'Empire' cracking was worse when AMS was added to the PC spray mixture than when it was omitted (Butch Palmer, ACDS Research, Williamson, N.Y., unpublished data).

A similar 'Empire' fruit injury has been attributed to a tank mix of captan fungicide with $CaCl_2$ or surfactants under slow drying conditions (Rosenberger, 1999). The captan label cautions that necrotic spotting of newly formed foliage can occur on sensitive cultivars when this fungicide is applied at high rates under slow drying conditions, but makes no mention of fruit damage. Users are cautioned against the use of spreader-stickers, and are advised to avoid tank-mixing captan with sulfur, oil, or "solvent formulations" of other pesticides.

'Empire' is widely planted throughout eastern North America, and there are many instances when it would be desirable to manage tree vigor using PC. The objectives of this study were 1) to evaluate the effect of hard water, with and without water conditioners, on the efficacy of vegetative growth reduction and incidence of 'Empire' fruit cracking caused by PC; and 2) to evaluate the effect of surfactants, captan, and $CaCl_2$ on the efficacy of growth reduction and incidence of 'Empire' fruit cracking caused by PC.

Materials and Methods

Expt. 1. Hard water and water conditioners, Highland, N.Y. This experiment was conducted on 9-year-old 'Empire'/M.26 apple trees that were trained to a central leader and spaced 3 m in the row and 6.1 m between rows. Total water hardness was measured with a digital titrator (model HA-DT; Hach Co., Loveland, Colo.). Water for the soft water treatments was obtained from a surface-fed pond, and averaged 58 mg·L^{-1} calcium carbonate ($CaCO_3$) equivalents. Hard water was obtained from a drilled well and averaged 222 mg·L^{-1} $CaCO_3$ equivalents.

The treatments were: 1) untreated control; 2) AMS in soft water; 3) PC in soft water; 4) PC in hard water; 5) PC in hard water and AMS; and 6) PC in hard water and Choice (Loveland Industries, Greeley, Colo.), a proprietary water conditioner composed of salts of polyacrylic, hydroxy carboxylic and proprionic acids, and phosphate ester, and AMS. Chemical rates were: PC 62.5 mg·L^{-1}, AMS 1.2 g·L^{-1}, and Choice 4.9 mL·L^{-1}. All treatments were applied by handgun to drip, and included Regulaid (polyoxyethylenepolypro-poxypropanol and alkyl 2-ethoxyethanol dihydroxy propane; Kalo, Overland Park, Kans.) at 0.125% (v/v). The first application was made on 7 May 2001, when terminal shoot growth averaged 3 cm. At the time of application the temperature was 22 °C, with relative humidity of 45%. The second application was made on 24 May, with temperature 18 °C, and relative humidity at 84%. The experiment utilized a randomized complete-block design with six replications.

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To adjust crop load, carbaryl (Sevin XLR Plus, Aventis, Research Triangle Park, N.C.) was applied at 600 mg·L^{-1} active ingredient (a.i.) at petal fall, and NAA (Fruitone N; Amvac Chemical Corp., Newport Beach, Calif.), was applied at 7.5 mg·L^{-1} a.i. on 16 May 2001. After June drop and evaluation of fruit set, the crop was hand thinned to a single fruit per cluster, spaced 15 cm apart.

Trunk circumference was measured at 30 cm above the ground at the beginning and end of the growing season and cross-sectional area (TCSA) was calculated. Ten terminal shoots on each tree were tagged at the start of the experiment and growth was measured bi-weekly, starting on 30 May. The total length of five water sprouts collected from the central leader of each tree was measured after seasonal growth was complete.

Fruit set was counted on one representative scaffold limb per tree on 11 July, after June drop was complete. Limb circumference was measured, and the number of fruit set per square centimeter of limb cross-sectional area was calculated.

The number of fruit and the yield of each tree were recorded at harvest. All the harvested fruit were evaluated for presence of defects or injury, and the ratio of fruits meeting the standard for U.S. Dept. of Agriculture (USDA) Extra Fancy was calculated. All the harvested fruit were divided into four size categories, based on diameter: <6.35 cm, 6.35–6.9 cm, 7.0–7.6 cm, and >7.6 cm, and the ratio of fruit in each size category was calculated.

Fruit quality at harvest was further assessed using 20 fruit sampled randomly from the periphery of each tree. Fruit length, weight and diameter were measured, and the length to diameter ratio (L/D) calculated. The severity of fruit injury was rated on the following scale: 1 = no visible injury; 2 = mottled/russeted skin with no corking; 3 = mottled/russeted skin plus one or two cork spots; 4 = several cork spots and zero to one small crack in the skin; 5 = many cork spots with several cracks.

Analysis of variance (ANOVA) was used to determine significance of treatments. Means were separated by Duncan's multiple range test.

Expt. 2. Hard water and water conditioners, Pittstown, N.J. This experiment was conducted on 11-year-old 'Empire'/M.26 apple trees that were trained to a central leader and spaced 3.7 m in the row and 6.1 m between rows. The calculated water volume for making a dilute spray application was 2337 L·ha^{-1}. Total water hardness was measured with a digital titrator, as previously described. Water for the soft water treatments was obtained from a drilled well, and averaged 42 mg·L^{-1} $CaCO_3$ equivalents. The addition of $CaCl_2$ at 2.6 g·L^{-1} was used to simulate hard water and raised the water hardness to 1000 mg·L^{-1} $CaCO_3$ equivalents.

The treatments were: 1) untreated control; 2) AMS in soft water; 3) PC (Apogee) in soft water; 4) PC in hard water; and 5) PC in hard water and AMS. Treatments were applied using an air-blast sprayer calibrated to apply 1543 L·ha^{-1} (1.5× concentration), and all applications included Regulaid spreader-activator at 0.125% (v/v). Applications were made on 10 May and 24 May 2001. The temperature at the time of the first and second applications was 26 °C and 19 °C, with relative humidity of 35% and 61%, respectively. Dilute concentrations of the chemicals were those used in experiment one. Since the spray volume was only 66% of the dilute tree row volume, the concentration of PC was increased 1.5×. The water conditioner (AMS) and the surfactant (Regulaid) were not concentrated. A randomized complete-block design with six replications was utilized.

To adjust crop load, a single application of carbaryl was applied at 600 mg·L^{-1} a.i. at petal fall, on 11 May. Water volume was 1543 L·ha^{-1} (66% of dilute tree row volume) and the carbaryl was concentrated 1.5×.

Data collection and analyses were conducted as previously described, with the exception that fruit set was not assessed by limb counts. Instead, fruit number per tree was counted at harvest, and crop load (fruit no./TCSA) was calculated.

Expt. 3. Surfactants, $CaCl_2$ and captan, Geneva, N.Y. This experiment was conducted on 9-year-old 'Empire'/M.9 and M.7 apple trees that were trained to a vertical axis system and spaced 2.4 m in the row and 4.9 m between rows. Spray water used was from the town of Seneca water supply derived from Seneca Lake and had a water hardness of 260 mg·L^{-1} $CaCO_3$ equivalents.

The treatments were: 1) untreated control; 2) PC (Apogee) + Quest (a proprietary water conditioner blend of ammonium salts of polyacrylic, hydroxy carboxylic and phosphoric acids; Helena Chemical Co., Collierville Tenn.); 3) PC + Quest + Regulaid; 4) PC + Quest + Regulaid + AMS; 5) PC + Quest + Regulaid + AMS + Silwet L77, a proprietary silicone-polyether copolymer (Loveland Industries, Greeley, Colo.); 6) PC + Quest + Regulaid + AMS + captan fungicide (N-Trichloromethylthio-4-cyclohexine-1,2-dicarboxymide, Captec 4L, Micro Flo Co., Memphis, Tenn.); 7) PC + Quest + Regulaid + AMS + $CaCl_2$ (Stopit, Pace Intl., Seattle, Wash.) 8) PC + Quest + Regulaid + AMS + captan + $CaCl_2$; and 9) PC + Quest + Regulaid + AMS + Silwet L77 + captan + $CaCl_2$.

Chemical rates were: PC 250 mg·L^{-1} a.i., Quest 2.5 mL·L^{-1}, AMS 0.9 g·L^{-1}, $CaCl_2$ (Stopit 4 mL·L^{-1}), 1.5 kg·ha^{-1} of Ca, Regulaid 1.25 mL·L^{-1}, Silwet L77 2.5 mL·L^{-1}, and captan 1.2 g·L^{-1} a.i. The first application was made on 14 May 2001, when terminal shoot growth averaged 4 cm. The second application was made on 5 June. Treatments were applied using an air-blast sprayer calibrated to apply 936 L·ha^{-1}. Dilute tree row volume was 2340 L·ha^{-1}. Since the spray volume was only 40% of the dilute tree row volume, all chemicals except the water conditioner (Quest) and the surfactants (Regulaid, and Silwet) were concentrated 2.5×.

The experimental design was a randomized complete block, split plot with four replications. Blocking was based on location in the field. The main plot was rootstock and the subplot was spray treatment. Each subplot consisted of four test trees guarded on each side by buffer trees.

To adjust crop load, a spray of Accel (Valent, USA, North Chicago) at 75 mg·L^{-1} a.i. plus carbaryl (Sevin XLR Plus; Aventis, Research Triangle Park, N.C.) at 600 mg·L^{-1} a.i. was applied on 23 May 2001 when king fruit diameter was 12 mm. Water volume was 936 L·ha^{-1} (40% of dilute tree row volume) and chemicals were concentrated 2.5× .

Trunk circumference was measured at the beginning of the season at 30 cm above the ground. Average shoot length was evaluated at the end of the season by measuring the length of five terminal shoots in the lower half of each test tree and five terminal shoots in the upper half of each tree (water sprouts were not measured). At harvest fruit number, yield and fruit drop were measured. Crop load and fruit size were calculated from fruit counts, yield and trunk circumference measurements. A 100-apple random sample from each subplot was collected at harvest and evaluated in January for red color and injury as previously described. The fruit from the sample were graded with a computerized color sorter and weight sizer (MAF Industries, Traver, Calif.). The fruit color and size distribution data were used to calculate the estimated gross value of the crop, using farm gate values of $10.00 per box of U.S. XF fruit >7.6 cm in diameter, $6.00 per box of U.S. XF fruit between 7.0–7.6 cm in diameter, $3.00 per box of U.S. F fruit between 6.4–6.9 cm in diameter, and -$2.90 per box of fruit that was <6.4 cm in diameter or less than U.S. F grade based on color or blemishes.

Data were analyzed by ANOVA to determine significance of treatments. Means were separated by Duncan's multiple range test. In addition, single degree of freedom contrasts were used to evaluate the effect of different chemicals.

Results

Expt. 1. Hard water and water conditioners, Highland, N.Y. All PC treatments caused an initial reduction in shoot growth on 31 May (Table 1). From 26 June to 24 July, bi-weekly shoot measurements showed PC combined with either water conditioner had the least growth, followed by PC in soft water, which had less growth than PC in hard water, and control trees had the greatest shoot growth. Curiously, AMS applied with Regulaid in soft water also provided some shoot growth control. At the end of the growing season (13 Oct.), PC combined with either water conditioner still provided more growth control than when PC was applied without a conditioner, even when a soft water source was used. PC had no effect on the growth of water sprouts.

PC had no effect on fruit set, yield, yield efficiency, fruit number per tree, crop load or fruit size distribution (data not presented). Preharvest fruit drop was negligible in this study and unaffected by treatment (data not presented).

PC had no effect on fruit weight or fruit diameter (data not presented). PC applied

Table 1. Effect of prohexadione-calcium (PC), water hardness, and water conditioners on shoot length and fruit injury of 'Empire' apple in Highland, N.Y., in 2001.

Treatment			Shoot length (cm)						Water sprout	Fruit	Damaged
PC	Water	Water									
(mg·L^{-1})	hardness[z]	conditioner[y]	31 May	13 June	26 June	10 July	24 July	13 Oct	length (cm)	injury rating[x]	fruit (%)[w]
Control	---	---	20 a[v]	29 a	37 a	38 a	38 a	39 a	107 a	2.5 d	49 b
0	58	AMS	17 b	24 b	31 b	31 b	31 b	31 b	102 a	2.7 c	50 b
63	58	0	17 b	21 cd	26 c	28 c	28 c	29 b	92 a	2.8 bc	60 b
63	222	0	17 b	22 bc	29 b	31 b	31 b	31 b	85 a	2.9 a–c	57 b
63	222	AMS	16 b	19 de	24 d	25 d	25 d	25 c	104 a	3.0 ab	77 a
63	222	Choice	15 b	18 e	23 d	24 d	24 d	25 c	104 a	3.1 a	79 a

[z]Water hardness is expressed as mg·L^{-1} of $CaCO_3$.
[y]AMS is ammonium sulfate applied at 1.2 g·L^{-1}. Choice water conditioner applied at 4.9 mL·L^{-1}.
[x]Fruit injury rated from 1 = none to 5 = many cork spots with several cracks.
[w]Total fruit damage includes damage caused by hail.
[v]Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.

with hard water, with or without AMS slightly increased the L/D ratio of fruit compared to untreated controls, (0.83 vs. 0.81, $P \leq 0.05$). All PC treatments increased the extent of fruit injury compared to the untreated controls (Table 1). AMS without PC also caused a small but significant increase in injury rating of fruit samples. Fruit damage was high for all treatments in this experiment due to early hail that damaged nearly half the fruit on all trees. PC combined with either water conditioner increased the amount of fruit damage, however PC without a conditioner or AMS without PC had no effect on the amount of fruit damage.

Expt. 2. Hard water and water conditioners, Pittstown, N.J. All PC treatments reduced shoot growth in this study, but to different degrees (Table 2). Growth of terminal shoots of trees treated with PC in soft water or with PC in hard water plus AMS was least, followed by that of PC in hard water. Shoot growth for trees treated with AMS without PC was greater than that of untreated controls, the opposite result of the previous study. PC did not affect water sprout length.

PC had no effect on total number of fruit per tree (data not presented). Crop load was reduced by PC in hard water, with and without AMS (Table 3). Preharvest fruit drop was severe on PC-treated trees, and those treated with PC in soft water had the most drop. The number and yield of harvested fruit on PC treated trees was reduced markedly by the amount of preharvest drop. PC had no effect on fruit size distribution of the harvested fruit (data not presented).

Trees treated with PC in soft water had smaller average fruit size, otherwise fruit size was unaffected by PC (Table 4). Fruit shape was unaffected by PC. Fruit from trees treated with PC had more severe corking and cracking than fruit from trees treated with AMS without PC or untreated trees. The severity of fruit corking and cracking was greatest for PC in soft water. All fruit that dropped prior to harvest showed fruit cracking, and when these were added to the number of hand harvested fruit with cracking, PC treated trees had more damaged fruit than untreated trees. The total amount of damaged fruit was greatest with PC in soft water, while AMS without PC did not increase fruit cracking.

Expt. 3. Surfactants, $CaCl_2$ and captan, Geneva, N.Y. Rootstock did not affect shoot growth, yield, fruit size, fruit drop, fruit color or fruit injury rating (Table 5). Trees on M.9 rootstock had greater crop load and yield efficiency than trees on M.7 rootstock. There were no significant interactions among rootstocks and spray treatments.

All of the PC plus Quest (PC/Q) treatments with the exception of the PC/Q and Regulaid treatment caused a significant reduction in shoot length in the lower half of the tree canopy, while all of the treatments reduced shoot length in the top of the tree (Table 5). Shoot length in the tops of untreated trees was much longer than shoot length in the bottoms of untreated trees. On PC/Q treated trees, shoot length in the bottom and tops of the trees were similar. The use of contrast analysis showed that the addition of Regulaid, AMS, Silwet, $CaCl_2$ or Captan did not affect the growth control obtained from PC/Q used alone.

None of the PC/Q treatments affected fruit number per tree, yield, or crop load relative to the control (Table 5). However, the PC/Q plus Regulaid treatment increased fruit number, yield, and crop load compared to several other PC/Q treatments. Contrast analysis showed that the addition of AMS to the PC/Q treatments resulted in lower crop load where PC/Q plus Regulaid was used.

PC/Q did reduce fruit size and yield efficiency. Contrast analysis showed that the addition of either Silwet or $CaCl_2$ to PC/Q treatments partially reversed the negative effect of PC/Q on fruit size. PC/Q increased preharvest fruit drop. Contrast analysis showed that the addition of either Silwet or $CaCl_2$ to the PC/Q treatments partially reversed the undesirable effect of PC/Q on fruit drop.

PC/Q sprays had no effect on fruit red color or percentage of fruit in the Extra Fancy grade (Table 6). Fruit injury was greatest in treatments that included captan, while the untreated control had the least injury. The other PC/Q treatments were intermediate in the extent of fruit injury, but many were not different from the control. Contrast analysis showed that the primary cause of fruit damage was PC plus Quest and that the effects of the other chemicals were nonsignificant. Several PC treatments increased fruit rots following storage, due to the cracking on the fruit. Fruit treated with PC plus Quest had the greatest amount of rot, while the untreated control had the least.

A packout analysis of fruit samples showed that all PC treatments with the exception of PC/Q plus Regulaid reduced the yield of undamaged fruit and all PC treatments reduced the yield of large fruit. The gross crop value was reduced by all PC treatments. None of the spray additives affected gross crop value.

Discussion

In the Hudson Valley trial, adding a water conditioner increased the ability of PC to reduce shoot growth compared to PC with either hard or soft water (Table 1), suggesting that a water conditioner is beneficial when low rates of PC are used, even when the initial hardness of the spray water source is low. AMS and Choice were equally effective water conditioners when used as described.

In addition to conditioning hard water, AMS as well as other ammonium salts are known to increase the absorption of plant growth regulators, such as napthaleneacetic acid (NAA) (Horsfall and Moore, 1961, 1962). Fader and Bukovac (2001) reported that adding ammonium nitrate to the solution enhanced cuticular penetration of NAA under low humidity. The

Table 2. Effect of prohexadione-calcium (PC), water hardness, and water conditioners on shoot length of 'Empire' apple in New Jersey, 2001.

Treatment			Shoot length (cm)							Water sprout
PC	Water	Water								length
(mg·L^{-1})	hardness[z]	conditioner[y]	25 May	11 June	25 June	9 July	20 July	3 Aug.	14 Nov.	(cm)
Control	---	---	17 b[x]	23 b	26 b	27 b	27 b	28 b	28 b	83 a
0	42	AMS	20 a	27 a	31 a	33 a	33 a	34 a	34 a	111 a
63	42	0	15 c	16 d	17 d	18 d	18 d	19 d	20 d	92 a
63	1000	0	17 b	19 c	21 c	22 c	22 c	23 c	24 c	125 a
63	1000	AMS	15 c	17 d	19 cd	19 d	19 d	20 d	21 d	109 a

[z]Water hardness is expressed as (mg·L^{-1} of $CaCO_3$).
[y]AMS is ammonium sulfate applied at 1.2 g·L^{-1}. Choice water conditioner applied at 4.9 mL·L^{-1}.
[x]Mean separation within columns by Duncan's new multiple range test, $P = 0.05$.

Table 3. Effect of prohexadione-calcium (PC), water hardness, and water conditioners on fruit size and yield of ‘Empire’ apple in New Jersey in 2001.

	Treatment			Harvested fruit/tree		
PC ($mg·L^{-1}$)	Water hardness[z]	Water conditioner[y]	Crop load (no./cm^2 TCSA[x])	(no.)	(kg)	Preharvest drop (%)
Control	---	---	12.1 a[w]	1522 a	209 a	7 c
0	42	AMS	11.1ab	1419 ab	190 a	13 bc
63	42	0	10.5 a–c	999 c	94 d	45 a
63	1000	0	9.6 bc	1326 a–c	163 bc	21 b
63	1000	AMS	8.5 c	1157 bc	134 cd	22 b

[z]Water hardness is expressed as mg $CaCO_3·L^{-1}$.
[y]AMS is ammonium sulfate applied at 1.2 $g·L^{-1}$.
[x]TCSA = trunk cross-sectional area.
[w]Mean separation within columns by Duncan’s new multiple range test, $P = 0.05$.

first PC spray in the Hudson Valley was applied under low relative humidity (45%), so the effect of ammonium on leaf absorption may explain why AMS improved the efficacy of PC in this study. The first PC spray in New Jersey was also applied under low relative humidity (35%), however the addition of AMS did not improve growth control of PC compared to the PC in soft water treatment, suggesting that absorption of PC was not a limiting factor in this study.

PC provided no growth control of water sprouts at either location (Tables 1 and 2). PC must be applied prior to the first flush of terminal shoot growth in order to be effective (Byers and Yoder, 1999), so our timings of PC spray were too early to reduce the growth of adventitious shoots, which are initiated later. To limit the number of water sprouts in the canopy, the use of heading or stubbing back cuts (i.e. bench cuts) should be avoided when pruning.

PC had no effect on fruit set or yield, but it did reduce fruit size at Geneva and in one of the PC treatments in New Jersey (Tables 4 and 5). PC increased set in some previous studies (Greene, 1999; Unrath, 1999), while in others it had no effect (Byers and Yoder, 1999). Greene (1999) showed that fruit set increased linearly with increasing PC concentrations between 125–375 $mg·L^{-1}$. The concentration of 63 $mg·L^{-1}$ PC used in the Hudson Valley and New Jersey may have been too low to affect set.

PC has been studied on a number of commercially important apple cultivars over the past decade, including ‘Delicious’ (Byers and Yoder, 1999; Greene, 1996; Unrath, 1999), ‘Fuji’ (Byers and Yoder, 1999; Unrath, 1999), ‘Gala’ (Byers and Yoder, 1999), ‘Golden Delicious’ and ‘Rome’ (Yoder et al., 1999a; 1999b), ‘Granny Smith’ (Unrath, 1999), ‘Macoun’ and ‘McIntosh’ (Greene, 1999), ‘Stayman’ (Byers and Yoder, 1999), ‘Spartan’ and ‘York Imperial’ (Greene, 1996). There were no reports of fruit injury in any of these studies, including most notably with ‘Stayman’ (Byers and Yoder, 1999), which is prone to skin cracking. Yoder et al. (1999b) reported that a single application of 250 $mg·L^{-1}$ PC at petal fall had no effect on fruit finish of ‘Golden Delicious’ or ‘Rome’. Greene (1996) reported that PC caused some

Table 4. Effect of prohexadione-calcium (PC), water hardness, and water conditioners on fruit quality of ‘Empire’ apple in New Jersey in 2001.

	Treatment						
PC ($mg·L^{-1}$)	Water hardness[z]	Water conditioner[y]	Fruit wt (g)	Fruit diam (mm)	Fruit L/D ratio	Fruit injury rating[x]	Total fruit damage (%)
Control	---	---	142 a[w]	6.9 a	0.87 a	1.5 c	12 c
0	42	AMS	141 a	6.9 a	0.86 a	1.8 c	20 c
63	42	0	130 b	6.6 b	0.87 a	4.3 a	69 a
63	1000	0	137 ab	6.8 a	0.86 a	3.1 b	33 b
63	1000	AMS	140 a	6.9 a	0.86 a	3.2 b	41 b

[z]Water hardness is expressed as ($mg·L^{-1}$ of $CaCO_3$).
[y]AMS is ammonium sulfate applied at 1.2 $g·L^{-1}$.
[x]Fruit injury rated from 1 = none to 5 = many cork spots with several cracks.
[w]Mean separation within columns by Duncan’s new multiple range test, $P = 0.05$.

Table 5. Effect of prohexadione calcium (PC) on shoot growth, crop load, yield and fruit size of ‘Empire’ apple trees on two rootstocks at Geneva, N.Y.

			Avg shoot length							
Stock	Treatment no.	Apogee (PC) treatment[z]	Lower half of tree (cm)	Upper half of tree (cm)	Fruit no. per tree	Yield per tree (kg)	Avg. fruit size (g)	Cropload (no. fruit/cm^2 TCSA)	Yield efficiency (kg fruit/cm^2 TCSA)	Fruit drop (%)
M.7			32.6 a[y]	31.8 a	333 a	49.9 a	151 a	3.34 b	0.50 b	23 a
M.9EMLA			31.4 a	34.9 a	367 a	57.5 a	158 a	8.24 a	1.28 a	21 a
	1	Untreated Control	35.7 a	50.5 a	352 a–c	59.7 a	170 a	5.88 a–d	1.01 a	17.7 c
	2	Apogee + Quest	31.0 b	31.0 b	375 ab	55.5 ab	149 c–e	5.90 a–d	0.88 a–c	22.2 ab
	3	Apogee + Quest + Regulaid	33.3 ab	32.3 b	410 a	59.9 a	147 de	6.74 a	0.99 ab	25.5 a
	4	Apogee + Quest + Regulaid + AMS	31.0 b	31.8 b	350 bc	51.4 b	146 de	5.74 a–d	0.84 c	24.8 a
	5	Apogee + Quest + Regulaid + AMS + Silwet	32.1 b	31.8 b	307 c	47.4 b	156 b–d	5.15 cd	0.80 c	19.6 bc
	6	Apogee + Quest + Regulaid + AMS + Captan	30.0 b	29.9 b	367 a–c	52.2 ab	142 e	6.19 ab	0.87 bc	25.5 a
	7	Apogee + Quest + Regulaid + AMS + $CaCl_2$	31.6 b	31.9 b	327 bc	51.4 b	159 bc	5.44 b–d	0.86 bc	19.6 bc
	8	Apogee + Quest + Regulaid + AMS + Captan + $CaCl_2$	32.1 b	29.8 b	349 bc	55.4 ab	159 bc	6.14 a–c	0.98 ab	19.7 bc
	9	Apogee + Quest + Regulaid + AMS + Silwet + Captan + $CaCl_2$	31.1 b	31.3 b	315 bc	50.7 b	162 ab	4.99 d	0.81 c	20.9 bc
		Contrasts for Apogee treatments ($P \le 0.05$)								
	(1 vs. 2)	Apogee + Quest Effect	***	*	NS	NS	***	NS	*	*
	(2 vs. 3)	Regulaid Effect	NS	NS	NS	NS	NS	NS	NS	NS
	(3 vs. 4)	Ammonium Sulfate Effect	NS	NS	*	*	NS	*	*	NS
	(4 vs. 5)	Silwet Effect	NS	NS	NS	NS	*	NS	NS	**
	(4 vs. 6)	Captan Effect	NS	NS	NS	NS	NS	NS	NS	NS
	(4 vs. 7)	$CaCl_2$ Effect	NS	NS	NS	NS	**	NS	NS	**
	(4 vs. 8)	$CaCl_2$ + Captan Effect	NS	NS	NS	NS	**	NS	*	**
	(4 vs. 9)	$CaCl_2$ + Captan+Silwet Effect	NS	NS	NS	NS	***	NS	NS	*

[z]Tree Row Volume = 2339 $L·ha^{-1}$. Spray volume = 935 $L·ha^{-1}$. Apogee, AMS, Captan and $CaCl_2$ concentrated 2.5× dilute rate. Apogee dilute rate = 0.92 $g·L^{-1}$, AMS dilute rate = 0.92 $g·L^{-1}$, Captan dilute rate = 2.5 $mL·L^{-1}$, $CaCl_2$ (Stopit) dilute rate = 4.0 $mL·L^{-1}$. Surfactants and water conditioners were not concentrated. Quest rate = 2.5 $mL·L^{-1}$, Regulaid rate = 1.25 $mL·L^{-1}$, Silwet rate = 2.5 $mL·L^{-1}$.
[y]Mean separation within columns in each section by Duncan’s new multiple range test, $P \le 0.05$.
[NS]Nonsignificant.

Table 6. Effect of prohexadione calcium (PC) on fruit quality of 'Empire' apple trees on two rootstocks at Geneva, N.Y.

Stock	Treatment no.	Apogee (PC) treatment[z]	Fruit surface with red color (%)	Fruit with XF grade (%)	Damaged fruit (%)	Avg fruit injury rating[y]	Rotten fruit (%)	Yield undamaged fruit ($T\cdot ha^{-1}$)	Yield large fruit (>7.6cm) ($T\cdot ha^{-1}$)	Gross return ($/ha)
M.7			72.2 a[x]	69.6 a	33.1 a	1.9 a	13.9 a	28.0 a	13.1 a	7,641 a
M.9EMLA			73.8 a	73.6 a	33.8 a	1.9 a	13.9 a	32.0 a	17.2 a	9,571 a
	1	Untreated control	73.9 a	73.1 a	26.0 b	1.7 b	7.8 b	37.8 a	25.2 a	14,189 a
	2	Apogee + Quest	74.5 a	74.8 a	36.8 ab	2.0 ab	21.1 a	29.6 b	13.3 bc	7,500 bc
	3	Apogee + Quest + Regulaid	74.0 a	74.6 a	26.8 b	1.7 b	12.1 ab	36.5 a	16.2 b	10,035 b
	4	Apogee + Quest + Regulaid + AMS	73.7 a	73.0 a	33.1 ab	1.9 ab	13.7 ab	28.3 b	12.3 bc	7,060 bc
	5	Apogee + Quest + Regulaid + AMS + Silwet	72.6 a	71.7 a	33.8 ab	1.9 ab	12.6 ab	26.2 b	13.4 bc	7,584 bc
	6	Apogee + Quest + Regulaid + AMS + Captan	72.9 a	70.9 a	39.6 a	2.1 a	14.8 ab	26.5 b	10.1 c	5,614 c
	7	Apogee + Quest + Regulaid + AMS + $CaCl_2$	70.0 a	64.8 a	30.1 ab	1.8 ab	18.2 a	30.0 b	15.9 b	9,474 b
	8	Apogee + Quest + Regulaid + AMS + Captan + $CaCl_2$	73.2 a	72.7 a	39.8 a	2.1 a	8.2 b	27.6 b	14.9 bc	7,732 bc
	9	Apogee + Quest + Regulaid + AMS + Silwet + Captan + $CaCl_2$	71.9 a	69.0 a	35.2 ab	1.9 ab	16.4 ab	27.5 b	15.1 bc	8,276 bc
		Contrasts for Apogee treatments ($P \leq 0.05$)								
	(1 vs. 2)	Apogee + Quest effect	NS	NS	*	*	**	**	***	***
	(2 vs. 3)	Regulaid effect	NS	NS	NS	NS	*	*	NS	NS
	(3 vs. 4)	Ammonium sulfate effect	NS	NS	NS	NS	NS	*	NS	NS
	(4 vs. 5)	Silwet effect	NS	NS	NS	NS	NS	NS	NS	NS
	(4 vs. 6)	Captan effect	NS	NS	NS	NS	NS	NS	NS	NS
	(4 vs. 7)	$CaCl_2$ effect	NS	NS	NS	NS	NS	NS	NS	NS
	(4 vs. 8)	$CaCl_2$ + Captan effect	NS	NS	NS	NS	NS	NS	NS	NS
	(4 vs. 9)	$CaCl_2$ + Captan+Silwet effect	NS	NS	NS	NS	NS	NS	NS	NS

[z]Tree Row Volume = 2339 $L\cdot ha^{-1}$. Spray volume = 935 $L\cdot ha^{-1}$. Apogee, AMS, Captan and $CaCl_2$ concentrated 2.5× dilute rate. Apogee dilute rate = 0.91 $g\cdot L^{-1}$, AMS dilute rate = 0.91 $g\cdot L^{-1}$, Captan dilute rate = 2.5 $mL\cdot L^{-1}$. $CaCl_2$ (Stopit) dilute rate = 4.0 $mL\cdot L^{-1}$. Surfactants and water conditioners were not concentrated. Quest rate = 2.5 $mL\cdot L^{-1}$ Regulaid rate = 1.25 $mL\cdot L^{-1}$, Silwet rate = 2.5 $mL\cdot L^{-1}$.

[y]Injury rating scale: 1 = no visible injury; 2 = mottled skin with no corking; 3 = mottled skin plus one or two cork spots; 4 = several cork spots and none or one small cracks in the skin; 5 = many cork spots with several cracks.

[x]Mean separation within columns in each section by Duncan's new multiple range test, $P \leq 0.05$.

[NS]Nonsignificant.

foliar injury to 'York Imperial' in one of two years' trials, otherwise, phytotoxicity has not been documented. Fruit injury caused by PC has been reported only for 'Empire'. The preharvest fruit drop from PC-treated trees documented in New Jersey (Table 3) and Geneva (Table 5) was attributed to premature ripening caused by the severe fruit cracking at these sites.

Fruit damage to 'Empire' was severe in all three of our trials, despite the use of the lowest labeled concentration of PC in two of the trials (Tables 1 and 4). Damage was exacerbated in one of the trials by the addition of a water conditioner (Table 1), however AMS applied with Regulaid, but without PC, had no effect on either the severity or extent of fruit injury. The addition of surfactants, $CaCl_2$ or captan to the PC treatments had no effect on the severity of the fruit damage. During previous trials by the authors, the use of PC on 'Empire' has not always resulted in fruit injury. The potential for PC injury on 'Empire' may be related to certain weather conditions, which we do not yet understand. Fruit cracking caused by PC increased preharvest drop in two of three experiments (Tables 3 and 5), and increased postharvest rot in the Geneva experiment where fruit were stored prior to grading (Table 6). From these results we conclude that the fruit injury is directly caused by the formulated product Apogee itself under certain environmental conditions, and that the potential economic consequences are so severe that this product should not be used on 'Empire'.

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