Controlling Growth of Bearing Apple Trees with Ethephon

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Abstract. Ethephon applied 12 to 26 days after full bloom at 1000 to 1500 mg·liter⁻¹ not only substantially inhibited apple (*Malus domestica* Borkh., spur 'Delicious' strains) tree growth but also caused fruit abscission. Gibberellin plus ethephon did not prevent fruit abscission when ethephon was used at these rates. Several low weekly doses of ethephon controlled tree growth without causing fruit abscission. Ethephon increased fruit soluble solids concentration and substantially reduced fruit starch in the application year. Ethephon greatly increased flowering and fruit set the following season. Fruit length : diameter ratio was not altered by the previous seasons' low weekly doses of ethephon. Chemical name used: (2-chloroethyl)phosphonic acid (ethephon).

Complete or partial fruit loss in high-density apple plantings due to a freeze can result in excessive shoot growth, which normally is controlled by the crop. Growth-retarding chemicals [butanedioic acid mono(2,2-dimethylhydrazide) (daminozide) and ethephon] applied to young apple trees have increased flower bud formation and retarded tree growth (Byers, 1976; Williams, 1972). These chemicals can be useful when trees have been planted too closely. The cancellation of daminozide's registration in 1989 left the fruit industry with no effective chemical method to control excessive tree growth in bearing trees. Ethephon applied at rates that retard tree growth also cause fruit abscission (Williams, 1972); this effect restricts its use to nonbearing trees. Ethephon is used commercially 2 to 3 weeks before harvest to increase red pigmentation in fruit and maturity of early harvest 'Delicious' apples (Hammett, 1976). Recently, however, ethephon has been used less due to the Environmental Protection Agency canceling the registration for daminozide and other preharvest drop control chemicals. However, ethephon could not be used alone because it caused fruit drop and hastened maturity (Unrath, 1972). In addition, when ethephon was applied in late summer at rates >500 mg·liter⁻¹ per application, flattening [length: diameter (L: D) ratio] occurred in 'Delicious' apples (Williams, 1975).

The objective of these experiments was to retard vegetative growth with ethephon without precipitating fruit abscission. In a previous experiment (unpublished), trees shaded for 3 days lost 87% of their fruit. Gibberellin (GA₄₊₇) sprays applied before, during, or 1 day after

the shade period prevented fruit abscission. Therefore, gibberellin was used in some of these experiments to reduce ethephon-induced fruit abscission.

Excessive tree growth can be a problem with any rootstock/scion combination when plantings are too dense for the soil and moisture supply. Four rootstock and spur 'Delicious' strains were used in these studies. Other cultivars/rootstocks, planting distances, and soil and moisture conditions would be expected to affect results from ethephon sprays, but these variables were not the primary focus of these experiments.

In 1990, 120 three-year-old 'Campbell Redchief Delicious'/M.26 trees were selected for tree size and growth uniformity. The trees were grown in a high-density three-row bed orchard where fruit count was seriously reduced by a freeze at bloom. There were six five-tree replications for each of four treatments in a randomized complete block design. Ethephon was sprayed on the vigorously growing top halves of the trees. The terminal shoot (central axis leader) was not sprayed within 30 cm of the shoot tip, nor were lower scaffolds where tree growth was desirable. Treatments (see Table 1) were applied on 8 May 1990, 12 days after full bloom. Fruit were counted on the top and bottom halves of the trees before application, and 43 days thereafter. The change in trunk circumference from 7 May 1990 to 15 Feb. 1991, terminal (central axis) shoot (nonsprayed) length, length of the top three side shoots (sprayed), number of lateral breaks >10 cm in length in the lower part of the tree, and the percentage of flowering spurs on the top and bottom halves of the trees were recorded in Apr. 1991.

Since the previous experiment was conducted in art orchard where the fruit crop was seriously damaged by prebloom freezes, another experiment was initiated in 1990 on trees with adequate fruit to study the retention effects of GA₄₊₇ on whole trees sprayed with ethephon. Five-year-old 'Ace Delicious'/M.7 trees (66 total) were selected for tree size and

crop load uniformity. There were six single-tree replications for each of 11 treatments in a randomized complete block design. Whole trees were sprayed. Ethephon was applied at 500, 1000, or 1500 mg·liter⁻¹, and GA₄₊₇ was applied at 50 or 100 mg·liter⁻¹ in the same tank. A delayed dormant superior oil (SunSpray 6E Oil; Sun Oil and Refining Co., Marcus Hook, Pa.) was used to determine its effect on penetration of combined growth regulators. In addition, on 5 June 1500 mg ethephon/liter was applied to whole trees to determine if a treatment after the normal thinning period would cause less fruit abscission than if applied earlier.

The numbers of fruit on each tree were counted 54 days after full bloom (AFB). Fruit density was expressed as the number of fruit per square centimeter of trunk cross-sectional area (TCA). Fruit diameter and seed viability were determined from a 10-fruit sample per tree collected near harvest. In Feb. 1991, the top three terminals on the central axis and the growth of the three longest scaffold branch shoots per tree were recorded, and in Apr. 1991, the percentage of flowering spurs and of axillary buds flowering on annual growth were visually estimated in the late-pink stage.

In 1991, a third experiment was initiated to compare multiple low doses of ethephon (100 or 200 mg·liter⁻¹) to a single high dose (1200 mg·liter⁻¹) on fruit abscission, tree growth, flowering, and fruit set the next season. Five-year-old trees (48 total) were selected for tree size and crop load uniformity. There were four single-tree replicates of 'Starkrimson Delicious'/MM.106 and four single-tree replicates of 'Starkrimson Delicious'/MM.111 for each of six treatments in a randomized complete block design. Trees were sprayed 26 days AFB. Fruit numbers per tree were counted before treatments were applied (15 May) and again on 4 June, 8 July, and 4 and 12 Aug.

Ten fruit were sampled from around each tree near harvest. Fruit diameter was determined with a band caliper; red pigmentation was visually estimated as the percentage of surface that was red; firmness was determined on two sides of each fruit with an Effegi penetrometer (model FT327; McCormick Fruit Tech, Yakima, Wash.) fitted with a 11.3-mm tip; and soluble solids concentration (SSC) was determined on a 10-fruit composite sample with an Atago hand-held refractometer (model ATC-1; McCormick Fruit Tech). Starch was rated by dipping one half of each fruit in iodine solution for 1 min; the degree of staining was rated on a scale of 1 to 5, where 1 = entire cut surface stained and 5 = no staining (Poapst et al., 1959). In addition, length of the top three central axis terminal shoots and TCA (calculated from trunk circumference) were determined. In Apr. 1992, the percentage of flowering spurs and of axillary buds flowering on annual growth was estimated in the late-pink stage. Also, the number of fruit set on each tree in 1992 was determined 30 days AFB. Fruit density was expressed as the number of fruit per square centimeter of TCA.

Fruit diameter and L: D ratios were determined in 1992 from samples collected from

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trees sprayed in 1991. All ethephon-treated trees set too many fruit and were thinned by hand to about seven fruit per square centimeter of TCA in 1992, but control trees did not have sufficient fruit for a full crop and, thus, L : D ratios may not be a valid comparison with ethephon treatments due to major differences in crop load.

Spot spraying the upper part of young 'Redchief Delicious' trees reduced percent fruit set in the lower and upper nonsprayed parts of the trees (Table 1). Ethephon reduced, relative to the control, trunk circumference, terminal shoot length (nonsprayed top terminal), and length of side shoots in the upper part of the tree (sprayed). The number of lateral breaks >10 cm long in the lower part of the tree increased even though total growth in the same area was unaffected. Percent flowering spurs in 1991 was not affected greatly by the treatments, probably because all trees were under-cropped in 1990 due to a freeze that

killed flowers at bloom. GA₄₊₇ in this experiment reduced flowering relative to ethephon alone (Table 1). However, without ethephon, 200 mg GA₄₊₇/liter greatly reduced flowering of 'Redchief Delicious'/M.26 bearing trees (unpublished).

Ethephon applied at 500 to 1500 mg-liter⁻¹ 20 days AFB, when fruit were 16 mm in diameter, caused most fruit to abscise (data not shown is due to inadequate sample size) (Table 2). GA₄₊₇, at 50 or 100 mg-liter⁻¹ reduced the number of abscised fruit per square centimeter of TCA when combined with 500 mg ethephon/liter, but was ineffective when combined with 1000 or 1500 mg ethephon/liter. Fruit diameter was larger in response to lower fruit per square centimeter of TCA. Ethephon plus GA₄₊₇ reduced viable seed counts. When viable and aborted seed were added together, little differences existed in total seed counts; thus, ethephon plus GA₄₊₇ caused seed abortion, but 500 ethephon/liter alone did not,

Ethephon reduced terminal and scaffold shoot length. Ethephon increased the percentage of flowering spurs and of axillary buds flowering on 1-year-old wood. The 5 June application of ethephon caused less fruit abscission than the earlier one. By this time, however, most terminal shoot growth was complete for the season. For this reason, ethephon must be applied early in the season to obtain better vegetative growth control. Adding Superior oil to the ethephon plus GA₄₊₇ combinations did not change the results.

Low doses of ethephon (100 or 200 mg-liter⁻¹) applied at weekly intervals starting 26 days AFB resulted in better fruit set than did a single 1200-mg-liter⁻¹ application at 26 and 103 days AFB (Table 3). Fruit diameter (75 to 77 mm), percent red surface (73% to 80%), and firmness (77 to 78 N) were not affected. However, the single 1200-mg-liter⁻¹ application in June (61 days AFB) significantly increased SSC and decreased starch levels. The low doses of

Table 1. Effect of ethephon and GA₄₊₇ on 'Campbell Redchief Delicious'/M.26 fruit set, tree growth, and flowering (1990–91).

Treatment ^{a, y}	Rate (mg-liter ⁻¹)	Fruit set(%) ^z		Trunk circumference increase 1991 (cm)	Terminal shoot length (cm) ^x	Avg length top three side shoots (cm) ^x	No. lateral breaks >10 cm on lower scaffolds	Total shoot length on lower scaffolds (cm) ^x	Spurs flowering (%) (Apr. 1991)	
		Upper	Lower	(Feb. 1991)	(Feb. 1991)	(Feb. 1991)			Top	Bottom
Control		84 a ^w	94 a	1.2 a	59 a	58 a	0.87 b	320 a	82 b	84 a
Ethephon	1500	3 b	12 c	0.8 b	23 b	19 b	2.13 a	338 a	92 a	92 a
Ethephon + GA	200	14 b	48 b	0.8 b	27 b	19 b	1.26 a	319 a	79 b	92 a
Ethephon + GA	1000	14 b	32 bc	0.8 b	31 b	21 b	1.16 a	310 a	80 b	84 a

^aSpray treatments were applied 8 May (12 days after full bloom) to the upper half of the tree, except for the terminal shoot, and no application was made to the lower half of the tree.

^yFull bloom occurred 26 Apr. 1990.

^zFor 1-year-old wood.

^wMean separation within column by Duncan's multiple range test, $P \leq 0.05$.

Table 2. Effect of ethephon and GA₄₊₇ on 'Ace Delicious'/M. 7 fruit set, tree growth, and flowering (1990–91).

Treatment ^{a, w}	Rate (mg-liter ⁻¹)	Fruit/cm ² TCA (+54 DAFB) ^u	Fruit diam (mm)	Viable seeds/ fruit (no.)	Total ^v seeds/ fruit (no.)	Viable seeds/ fruit (%)	Terminal shoot length (cm) ^x (Feb. 1991)	Scaffold shoot length (cm) ^x (Feb. 1991)	% Spurs flowering (19 Apr. 1991)	% Axillary buds ^y flowering (19 Apr. 1991)
Control		7.7 a ^t	71 b	3.2 b	4.5 ab	70 b	42 a	45 a	72 d	12 c
Ethephon	500	1.8 c	77 a	2.7 b	4.2 bc	63 b	35 ab	39 b	99 ab	49 d–f
	1000	0.03 d					25 c	24 d	100 a	87 ab
	1500	0.15 d					19 c	21 d	100 a	94 a
Ethephon + GA	50	4.7 b	72 b	1.4 c	4.1 bc	34 c			93 c	19 gh
Ethephon + GA	1000	0.51 d							100 a	69 b–d
Ethephon + GA	50	0.02 d							100 a	78 bc
Ethephon + GA	500									
+ oil	5000	6.6 a	74 ab	1.1 c	4.0 c	27 c	38 a	38 b	52 e	15 h
Ethephon + GA	1000									
+ oil	5000	1.0 cd							95 bc	33 f–h
Ethephon + GA	1500									
+ oil	5000	0.0 d							98 ab	57 c–e
Ethephon ^s	1500	4.3 b	74 ab	4.4 a	4.7 a	92 a	35 ab	36 bc	100 a	86 ab

^aIncludes viable and aborted seed.

^wFor 1-year-old wood.

^tAverage of three shoots.

^uSpray treatments were applied 16 May—20 days AFB when fruit diameter was 16.7 ± 0.72 mm.

^vFull bloom occurred 26 Apr. 1990.

^xTCA = trunk cross-sectional area; DAFB = days after full bloom.

^yMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^sApplied June 5—40 days AFB when fruit diameter was 30.5 ± 0.63 mm, which was 10 days after starch started accumulating in the fruit.

Table 3. Effect of ethephon on fruit set, fruit diameter, red color, firmness, soluble solids concentration (SSC), and starch of 'Starkrimson Delicious'/MM.111 and MM.106 (1991-92).

Ethephon concn ^{a, x} (mg·liter ⁻¹)	Application dates ^a												Fruit set (%)				SSC (%)	Starch rating
	May			June				July					Aug.				3 Sept.	3 Sept.
	15	22	30	6	12	19	26	3	10	17	24	31	4 June	8 July	4	12		
0													97 a ^w	97 a	97 a	97 a	11.6 c	2.0 d
100	x	x	x	x	x	x	x	x	x	x	x	x	97 a	97 a	97 a	97 a	14.3 ab	4.0 c
200	x	x	x	x	x	x							96 a	95 a	95 a	95 a	13.9 b	4.5 b
1200	x												0 b	0 b	0 d	0 c		
1200						x							98 a	85 b	84 b	84 b	14.6 a	5.0 a
1200												x	94 a	93 a	29 c	1 c		

^aApplication dates correspond to 26, 33, 41, 48, 54, 61, 68, 75, 82, 89, 96, and 103 days after full bloom.

^xData taken on four replications on MM.111 and four replications on MM.106 were pooled. Shoot length on the controls was 57 cm and trunk cross-sectional area was 5.6 cm².

^wFruit diameter was 17, 26, 33, 38, and 43 mm at 26, 33, 41, 48, and 54 days after full bloom, respectively.

^wMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

Table 4. Effect of ethephon on return bloom and tree growth of 'Starkrimson Delicious'/MM.111 and MM.106, 1991-92.

Ethephon concn ^{a, w} (mg·liter ⁻¹)	Application dates ^a												Length top		Return bloom (Apr. 1992)		Fruit/cm ²	Fruit	Length :
	May			June				July					three shoots	TCA ^y	Spurs	Nodes ^x	TCA	diam (mm)	diam
	15	22	30	6	12	19	26	3	10	17	24	31	(% control)	(% control)	flowering	flowering	(27 May 1992)	(13 Aug. 1992)	ratio
0													100 a ^z	100 a	68 d	2 d	2.7 c	68 a	0.90 ab
100	x	x	x	x	x	x	x	x	x	x	x	x	40 c	45 b	96 bc	24 ab	14.3 b	64 b	0.89 b
200	x	x	x	x	x	x							32 cd	55 b	98 ab	33 a	14.6 b	63 b	0.90 ab
1200	x												23 d	72 ab	100 a	30 a	22.4 a	62 b	0.92 a
1200					x								68 b	79 ab	94 c	11 c	13.4 b	63 b	0.91 ab
1200												x	104 a	95 a	93 c	13 bc	11.6 b	65 b	0.90 ab

^aApplication dates correspond to 26, 33, 41, 48, 54, 61, 68, 75, 82, 89, 96, and 103 days after full bloom, respectively.

^yTCA = trunk cross-sectional area.

^zFor 1-year-old wood.

^wFruit diameter was 17, 26, 33, 38, and 43 mm at 26, 33, 41, 48, and 54 days after full bloom, respectively.

^xData taken on four replications on MM.111 and four replications on MM.106 were pooled. Shoot length on the controls was 57 cm and trunk cross-sectional area was 5.56 cm².

^wMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

ethephon likewise increased SSC and reduced starch levels.

Low doses of ethephon greatly reduced shoot length and TCA (Table 4); however, a single June application was not as effective in controlling shoot length because growth had stopped by this time. Ethephon applied in 1991 (particularly early season low doses) greatly increased return bloom of spurs and 1-year-old wood in 1992 (Table 4). In 1992, fruit set was poor due to poor pollination and fertilization conditions at bloom and soon after. Trees treated with ethephon in 1991 had $\approx 200\%$ to 400% more fruit per square centimeter of TCA in 1992 than the control due to increased number of flowers per tree. Ethephon-sprayed trees had to be thinned by hand, whereas the control trees had $<50\%$ of a crop load. Fruit diameter of the control trees was larger due to the greater crop load. Ethephon applied in 1991 did not affect the fruit L:D ratio in 1992; however, since the control yield did not equal that of ethephon-treated trees, a valid comparison may not be possible.

In conclusion, spur 'Delicious' apple tree growth can be reduced by low doses of ethe-

phon applied primarily in the first 45 days AFB. However, a single high dose early in the season also controls tree growth, but fruit abscission occurs. When a single dose was applied later than 60 days AFB, little fruit abscission occurred; but, since the majority of shoot growth had already occurred, this application time was ineffective for tree growth control. Early season ethephon applications reduced starch levels and increased SSC in the current season but did not affect fruit firmness, shape, or size during the subsequent season. Flowering and fruit set were greatly increased the following season.

Additional studies are needed to determine the effects of early season ethephon applications on stored-fruit quality. Applying ethephon near harvest has been shown to reduce apple scald (Hammett, 1976; Lurie et al., 1989). Additionally, the response obtained by multiple applications of ethephon likely will be different for various cultivars, rootstock, tree age, soil and moisture conditions, and planting and pruning systems. Also, methods for monitoring growth suppression during weekly applications could be used to determine the num-

ber of applications needed to obtain the desired growth control and minimize chemical costs.

Literature Cited

- Byers, R.E. 1976. Chemical control of vegetative growth and flowering of non-bearing 'Delicious' apple trees. *HortScience* 11:506-507.
- Hammett, L.K. 1976. Ethephon influence on storage quality of 'Starkrimson Delicious' and 'Golden Delicious' apples. *HortScience* 11:57-59.
- Lurie, S., S. Meir, and R.B. Arie. 1989. Preharvest ethephon sprays reduce superficial scald of 'Granny Smith' apples. *HortScience* 24:104-106.
- Poapts, P.A., G.M. Ward, and W.T. Phillips. 1959. Maturation of McIntosh apples in relation to starch loss and abscission. *Can. J. Plant Sci.* 39:257-263.
- Unrath, C.R. 1972. Effects of preharvest applications of ethephon on maturity and quality of several apple cultivars. *HortScience* 7:77-79.
- Williams, M.W. 1972. Induction of spur and flower bud formation in young trees with chemical growth retardants. *J. Amer. Soc. Hort. Sci.* 97:210-212.
- Williams, M.W. 1975. Carry over effect of ethephon on fruit shape of 'Delicious' apples. *HortScience* 10:523-524.