Cytokinin and Ethephon Affect Crop Load, Shoot Growth, and Nutrient Concentration of 'Empire' Apple Trees

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Abstract. Benzyladenine (BA) applied postbloom at 125 and 250 mg·liter⁻¹ thinned 'Empire' apple (*Malus domestica* Borkh.) trees below commercial crop levels but thinned less than thidiazuron (THI) at 62 and 125 mg·liter⁻¹. Ethephon (ETH) applied up to 250 mg·liter⁻¹ reduced fruit set only slightly. When BA was tank-mixed with ETH, thinning was the same as with BA alone. Although THI thinned more, BA resulted in a larger increase in fruit weight. Seed development was nearly eliminated by THI, but was unaffected by either BA or ETH. Thinner effects on foliar nutrient concentrations were associated with changes in fruit load but not shoot growth. The effects of BA and ETH on fruit-flesh nutrient concentrations were similar to their effects on foliar nutrient concentrations. Although THI thinned strongly and produced large changes in foliar nutrient concentrations and seed count, THI resulted in virtually no changes in fruit-flesh nutrient concentrations. Chemical names used: *N*-(phenylmethyl)-1*H*-purine-6-amine (benzyladenine); 2-chlorophosphonic acid (ethephon); *N*-phenyl-*N'*-1,2,3-thiadiazol-5-ylurea (thidiazuron).

Chemically thinning apples postbloom improves fruit size, increases return bloom, and reduces cropping alternation (Forshey, 1987; Looney, 1986; Williams and Edgerton, 1981). The 'Empire' apple, widely planted in Ontario, is noted for its moderate fruit size and increased difficulty in thinning older trees (Forshey, 1990). Ethephon (ETH) has shown thinning properties on several apple cultivars (Jones et al., 1983, 1989; Knight, 1980; Knight et al., 1987; Keen et al., 1988). The cytokinins benzyladenine (BA) and *N*-(2-chloro-4-pyridyl)-*N'*-phenylurea (CPPU) also thin apple (Bound et al., 1991; Byers and Carbaugh, 1991; Elfving, 1989; Elfving and Cline, 1993; Greene, 1989; Greene and Autio, 1989; Greene et al., 1990). Cytokinins and ethephon also can affect vegetative growth, nutrient concentrations, and crop load (Elfving, 1984; Miller, 1988). Thidiazuron (THI) has been reported to have cytokinin-like activity in apple and other species (Fellman et al., 1987; Wang et al., 1986), but has not been studied as a chemical thinner for apple. The trials reported here evaluated BA, ETH, and THI for effects on

crop load, shoot growth, and nutrient concentrations of 'Empire' apple trees.

Field trials were conducted in 1989 and 1990 at the Horticultural Experiment Station, Simcoe, Ont., Canada. All thinning treatments were applied as dilute sprays to runoff with a hydraulic handgun sprayer. Total blossom cluster number, fruit set after June drop, shoot growth (≥ 5 cm long), and blossom cluster number the following spring were determined on one representative limb per tree (Forshey and Elfving, 1979). Limb circumference was

measured at a predetermined location at bloom, when shoot growth was measured in late August, and again the following spring. Trunk circumference was measured each year after leaf drop at a premarked location 30 cm above the soil surface.

Yield and mean fruit weight were determined by counting and weighing all fruit on each tree at harvest. In 1990, a 25-fruit sample was collected randomly from each tree at harvest. Fruit length and diameter were measured, and each fruit was sectioned equatorially to count normally developed seeds.

Midshoot leaves from current-season shoot growth were collected in Aug. 1989 and 1990 and analyzed according to the methods of Bodnar et al. (1983). Fruit samples were collected at harvest in 1990 and analyzed for nutrient concentrations using the same methods.

Experiment 1, 1989: BA and ETH. Twelve treatments each were applied in a factorial treatment arrangement to a separate set of five-replicate, 8-year-old 'Empire'/M.7 trees in a randomized complete-block design. Each treatment consisted of a tank mix of one concentration of the following two growth regulators: 1) BA at 0, 50, 100, or 150 mg (a.i.)/liter and 2) ETH at 0, 50, or 100 mg (a.i.)/liter. The control (0 BA + 0 ETH) was nontreated. Treatments were applied on 6 June [13 days after full bloom (DAFB)], when fruit diameter averaged 10.3 ± 0.9 mm. Trees were spaced 4.3×6.7 m on a moderately drained Tuscola silt loam consisting of mixed glaciolacustrine loams, silts, and very fine sandy loam (Hohner and Presant, 1989).

Experiment 2, 1990: BA, ETH, and THI. Seven treatments each were applied to seven-replicate, 7-year-old 'Empire'/M.26 trees in a randomized complete-block design: 1) control (no treatment), 2) BA at 125 or 250 mg (a.i.)/liter, 3) THI at 62 or 125 mg (a.i.)/liter, or

Table 1. Effects of both BA and ETH on flowering, fruit set, yield, trunk cross-sectional area (TCSA), and return bloom of 'Empire'/M.7 trees (Expt. 1).

BA/ETH ^a (mg·liter ⁻¹)	Fruit PCLA ^y	Per tree		Mean fruit wt (g)	TCSA increment, 1989 (cm ²)	Blossom clusters PCLA, 1990
		Fruit (no.)	Yield (kg)			
0/0	7.3	578	72	130	9.5	6.0
50/0	3.8	430	63	150	12.5	11.6
100/0	5.6	436	69	160	12.8	12.6
150/0	4.4	412	71	170	13.1	9.0
0/50	7.2	592	70	120	10.3	8.5
50/50	6.4	516	71	140	11.5	10.7
100/50	4.7	395	61	160	12.4	12.5
150/50	3.4	360	63	170	13.0	12.0
0/100	6.2	552	70	130	11.5	10.0
50/100	5.2	383	58	140	11.6	11.4
100/100	3.6	371	60	170	10.8	13.6
150/100	3.4	347	56	160	13.0	12.0
Significance						
BA						
L	****	****	NS	****	*	*
Q	NS	*	NS	*	NS	*
ETH						
L	NS	NS	*	NS	NS	*

^a0 BA + 0 ETH treatment was nontreated; each mean contains five observations.

^yPCLA = per square centimeter of limb cross-sectional area.

NS, ****Nonsignificant or significant at $P \leq 0.05$ or 0.0001 , respectively; L = linear and Q = quadratic by multiple regression analysis. Higher-order simple and interactive effects nonsignificant ($P \leq 0.05$).

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4) ETH at 125 or 250 mg (a.i.)/liter. Treatments were applied on 31 May (22 DAFB), when fruit diameter averaged 11.0 ± 2.5 mm. Trees were spaced 3.7×5.5 m on a well-drained Brant sandy loam consisting of a mixture of glaciolacustrine loams, silts, and fine sandy loam (Hohner and Presant, 1989).

Data from Expt. 1 were analyzed by multiple regression. Experiment 2 was analyzed using a radiating regression model described by Cochran and Cox (1957) and Elfving and Allen (1987). All analyses were carried out using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) program package (SAS Institute, Cary, N.C.). In both experiments, quadratic or cubic regression models were analyzed initially, as appropriate. Nonsignificant higher-order effects were incorporated into the error term of less-complex models, which were reanalyzed.

Experiment 1. Flowering at the start of the trial was uniform among treatments, averaging 11.4 blossom clusters per square centimeter of limb cross-sectional area (PCLA) (data not shown). Fruit set and fruit count per tree were reduced by higher BA concentrations but were unaffected by ETH (Table 1). In contrast, yield per tree was reduced at higher ETH concentrations but was unaffected by BA. Mean fruit weight was increased substantially by BA but was not affected by ETH. Initial trunk cross-sectional area (TCSA) was uniform among treatments and averaged 58 cm^2 /tree. Incremental trunk growth in 1989 increased with higher BA concentration, probably as a result of reduced crop load. Return bloom in 1990 was increased by BA and ETH.

Shoot count and length were increased and mean shoot length was decreased by BA, but shoot growth was unaffected by ETH (Table 2). Foliar K was increased and Ca decreased by BA, while N and Mg were unaffected by either chemical.

Experiment 2. Flowering at the start of the trial was uniform among treatments, averaging 17 blossom clusters PCLA. Fruit set and fruit count per tree were decreased by a higher concentration of each chemical (Table 3). Yield per tree was decreased and mean fruit weight increased only by BA and THI. Return bloom in 1991 was increased only by BA and ETH. Initial TCSA was uniform among treatments and averaged 58 cm^2 /tree. BA and THI increased incremental trunk enlargement in 1990, probably because of reduced crop load.

Fruit length and diameter were increased by BA and THI, but ETH had no effect (Table 4). BA slightly decreased the length:diameter (LD) ratio. THI nearly eliminated seed development, similar to CPPU at $100 \text{ mg-liter}^{-1}$ on 'McIntosh' apples treated 18 days after petal fall (Greene, 1989), about the same time THI was applied in 1990. BA and ETH had no effect on seed count. Reduced seed count can influence fruit shape (Proctor and Schechter, 1992), but no such effects were observed in this study.

BA increased fruit-flesh N and K and decreased P and Ca concentrations (Table 4). The effect of BA on fruit-flesh Mg concentration was curvilinear. ETH had no effect on

Table 2. Effects of BA and ETH on shoot growth and foliar nutrient concentrations of 'Empire'/M.7 trees (Expt. 1).

BA/ETH ^y (mg-liter ⁻¹)	Shoot growth PCLA ^z		Mean shoot length (cm)	Foliar macronutrients (% dry wt)			
	No.	Length (cm)		N	K	Ca	Mg
0/0	2.6	69	26	2.49	1.56	0.77	0.23
50/0	2.8	79	30	2.42	1.55	0.74	0.22
100/0	3.1	80	25	2.41	1.44	0.83	0.26
150/0	4.2	97	23	2.65	1.69	0.66	0.23
0/50	2.5	66	26	2.43	1.41	0.78	0.24
50/50	2.6	70	27	2.45	1.52	0.74	0.24
100/50	3.0	84	28	2.51	1.56	0.71	0.24
150/50	4.3	100	24	2.43	1.55	0.71	0.22
0/100	3.3	89	27	2.39	1.51	0.80	0.24
50/100	2.9	77	27	2.58	1.57	0.69	0.24
100/100	3.8	83	22	2.48	1.52	0.77	0.24
150/100	4.6	108	24	2.49	1.57	0.73	0.24
Significance							
BA							
L	****	**	*	NS	*	*	NS
Q	*	NS	NS	NS	NS	NS	NS

^zPCLA = per square centimeter of limb cross-sectional area.

^y0 BA + 0 ETH treatment was nontreated; each mean contains five observations.

NS,*,**,* ****Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively; L = linear and Q = quadratic by multiple regression analysis. ETH effects and higher-order simple and interactive effects nonsignificant ($P \leq 0.05$).

Table 3. Effects of BA, THI, or ETH on flowering, fruit set, yield, trunk cross-sectional area (TCSA), and return bloom of 'Empire'/M.26 trees (Expt. 2).

Treatment ^x (mg-liter ⁻¹)	Fruit PCLA ^y	Per tree		Mean fruit wt (g)	TCSA increment, 1990 (cm ²)	Blossom clusters PCLA, 1991
		Fruit (no.)	Yield (kg)			
Control	8.1	785	123	160	11.0	9.6
BA						
125	3.3	390	81	210	17.2	17.5
250	1.6	225	56	250	22.5	22.7
THI						
62	2.8	227	46	230	18.7	14.8
125	0.8	125	29	230	20.8	13.1
ETH						
125	5.8	625	106	170	13.6	13.8
250	4.9	543	96	180	15.0	15.0
Significance						
Concentration (C)	****	****	****	****	**	***
Growth regulator $\times$ C	****	****	****	****	*	***
BA	L****	L***, Q*	L****	L****	L***	L****
THI	L****	L****, Q****	L****, Q**	L****, Q****	L**	NS
ETH	L*	L*	NS	NS	NS	L*

^xEach mean contains seven observations.

^yPCLA = per square centimeter of limb cross-sectional area.

NS,*,**,* ****Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively; L = linear and Q = quadratic by radiating-regression analysis.

fruit-flesh N; effects similar to those of BA on fruit-flesh P, K, and Mg; and a curvilinear effect on fruit-flesh Ca concentration. THI effects on fruit-flesh nutrient concentrations were limited to an increase in fruit-flesh K concentration.

BA increased shoot count and length but did not affect mean shoot length (Table 5). THI and ETH did not affect shoot count or length, but both reduced mean shoot length similarly. THI significantly decreased foliar N, K, Ca, and Mg concentrations. Higher BA concentrations were accompanied by increased foliar K and decreased foliar Ca and Mg concentrations, but ETH did not influence foliar nutrient concentrations.

BA reduced 'Empire' fruit set in direct proportion to concentration up to $250 \text{ mg-liter}^{-1}$

with no negative effects on fruit size, shape, or seed development. Previous work with 'Empire' apple suggests that BA concentrations of 50 to $100 \text{ mg-liter}^{-1}$ thin adequately (Elfving and Cline, 1993). ETH thinning on 'Empire' trees was limited at concentrations up to $250 \text{ mg-liter}^{-1}$. Jones et al. (1989, 1991) reported acceptable thinning of 'Fuji' and 'Delicious' with ETH at 25 to $200 \text{ mg-liter}^{-1}$, but other reports suggest that higher concentrations are necessary to reduce crop load significantly (Jones et al., 1983; Keen and Jones, 1985). Tank-mixing ETH with BA did not change BA thinning behavior or produce interactive effects on vegetative growth or crop load. THI was much more active as a thinner than BA and nearly defruited trees treated with $125 \text{ mg-liter}^{-1}$.

Table 4. Effects of BA, THI, or ETH on fruit characteristics and fruit-flesh nutrient concentrations of 'Empire'/M.26 trees (Expt. 2).

Treatment ^a (mg·liter ⁻¹)	Fruit			Seeds/ fruit (no.)	Fruit-flesh nutrient concn (mg/100 g fresh wt)				
	Length (cm)	Diam (cm)	L : D ^b ratio		N	P	K	Ca	Mg
Control	6.5	7.2	0.90	5.5	35	8.2	64	5.1	4.2
BA									
125	6.7	7.9	0.86	5.6	32	7.8	68	4.1	3.9
250	7.3	8.2	0.89	4.9	40	5.4	110	4.6	4.4
THI									
62	7.2	8.0	0.91	0.9	31	7.9	83	4.3	4.3
125	7.3	8.0	0.91	0.6	37	8.9	117	4.2	4.5
ETH									
125	6.5	7.4	0.87	5.3	32	7.7	74	3.8	3.8
250	6.3	7.3	0.86	5.7	38	6.8	96	5.6	4.7
Significance									
Concn (C)	***	****	NS	****	*	*	****	**	**
GR ^c × C	****	****	**	****	NS	**	*	*	*
BA	L****	L****	L*, Q*	NS	L*	L**	L****	L*	Q*
THI	L***, Q*	L***, Q*	NS	L****, Q****	NS	NS	L****	NS	NS
ETH	NS	NS	NS	NS	NS	L*	L****	L**, Q***	L**, Q**

^aEach mean contains seven observations.

^bL : D = length : diameter ratio.

^cGR = growth regulator.

NS, *, **, ***, **** Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively; L = linear and Q = quadratic by radiating-regression analysis.

Table 5. Effects of BA, THI, or ETH on shoot growth and foliar nutrient concentrations of 'Empire'/M.26 trees (Expt. 2).

Treatment ^a (mg·liter ⁻¹)	Shoot growth PCLA ^b		Mean shoot length (cm)	Foliar macronutrients (% dry wt)			
	No.	Length (cm)		N	K	Ca	Mg
Control	3.0	70	24	2.63	1.29	1.09	0.31
BA							
125	3.9	97	24	2.58	1.48	1.00	0.28
250	5.2	104	19	2.57	1.64	0.90	0.27
THI							
62	2.7	55	19	2.11	1.77	0.82	0.24
125	2.5	50	21	2.10	1.90	0.85	0.24
ETH							
125	2.7	56	21	2.59	1.35	1.10	0.30
250	3.0	57	19	2.54	1.34	1.12	0.29
Significance							
Concentration (C)	*	NS	*	***	***	**	*
Growth regulator × C	****	****	NS	****	****	****	**
BA	L****	L**	L*	NS	L**	L**	L*
THI	NS	NS	L*	L****, Q****	L**, Q*	L****, Q****	L**, Q*
ETH	NS	NS	L*	NS	NS	NS	NS

^aPCLA = per square centimeter of limb cross-sectional area.

^bEach mean contains seven observations.

NS, *, **, ***, **** Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively; L = linear and Q = quadratic by radiating-regression analysis.

High-volume applications, such as those used in the trials reported here, favor the maximum thinning response to ETH (Jones et al., 1991). Jones and Keen (1985) reported a linear increase in ETH-induced thinning from 12 to 24°C. The daily temperatures during the week after applying ETH in 1989 and 1990 averaged 18 and 16°C, respectively. Ambient temperatures may have limited ETH thinning.

BA increased shoot growth in both experiments, as has been observed previously (Bound et al., 1991; Elfving and Cline, 1993; Greene and Autio, 1990; Greene et al., 1990). ETH has reduced shoot growth when applied at >350 mg·liter⁻¹ for thinning postbloom (Jones et al., 1983; Keen et al., 1988) but had little effect in these trials. Although THI exhibits cytokinin-like activity and thinned more than BA, THI did not increase shoot count but reduced mean

shoot length. In contrast, CPPU increased shoot length but not shoot count in 'McIntosh' apple trees (Greene, 1989). Shoot growth stimulated by BA did not impede increased return bloom in response to reduced crop load.

BA-induced changes in foliar K, Ca, and Mg concentrations seem to reflect its effects on crop load, although altered shoot growth may have contributed to the observed differences. Increased foliar K concentration, likely resulting from reduced fruit load, may have induced lower foliar Ca and Mg concentrations. THI produced similar and stronger changes in foliar K, Ca, and Mg concentrations, likely resulting from the strong thinning effect of this chemical. Decreased foliar N concentration after applying THI also may have resulted from reduced crop load.

BA and ETH generally altered fruit-flesh

nutrient concentrations similarly to foliar nutrient concentrations. Despite its strong influence on foliar nutrient concentrations and seed count, THI had almost no effect on fruit-flesh nutrient concentrations. Bramlage et al. (1990) reported a direct relation between seed count at harvest and fruit size or flesh Ca concentration in 'Delicious' apple. There was no relationship between seed count and fruit size or fruit-flesh concentration of any nutrient determined in this study.

The risk of overthinning 'Empire' apple trees with BA is limited by the wide range of concentrations over which thinning remains inversely proportional to concentration. Successfully thinning 'Empire' apples with ETH may require significantly higher concentrations and changes in application timing than used here (Keen and Jones, 1985). The excessive thinning, reduced foliar N concentration, and detrimental effects on seed development observed with THI in this study may be ameliorated by using lower concentrations.

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