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Benzyladenine and Other Chemicals for Thinning 'Empire' Apple Trees

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Abstract. **Postbloom applications of benzyladenine (BA) thinned young fruitlets of mature 'Empire' apple trees *(Malus domestica* Borkh.) as well as or better than NAA or carbaryl (CB). BA increased fruit weight more effectively than either NAA or CB. Promalin (PR) was less effective than BA for both thinning and fruit-weight increase. In 1990, both BA and PR reduced fruit set up to 29 days after full bloom, but PR showed less thinning activity. BA and NAA produced independent and additive thinning responses when tank-mixed. Effects of all thinners on foliar mineral-nutrient concentrations were associated with changes in fruit load. BA increased return bloom as much or more than NAA or CB. PR did not affect return bloom. Chemical names used: *N* -(phenylmethyl)-1 *H* -purine-6-amine [benzyladenine (BA)]; BA plus gibberellins A, and A, [Promalin (PR)]; 1-naphthaleneacetic acid (NAA); 1-naphthalenyl methylcarbamate [carbaryl (CB)].**

Chemical fruit thinning of apple following bloom is a standard practice to improve fruit size, increase return bloom, and reduce biennial cropping (Forshey, 1987; Looney, 1986; Williams and Edgerton, 1981). The thinners naphthaleneacetic acid (NAA) and carbaryl (CB) are used widely in Ontario and elsewhere (Elfving, 1989; Looney, 1983). Thinning results with NAA are often variable and may be complicated seriously by weather, spray volume, and additives (Ebert and Kreuz, 1988; Jones et al., 1988; Looney, 1986; Looney and McKellar, 1984; Williams and Edgerton, 1981). CB is harmful to beneficial arthropod species in the orchard, and its use is discouraged in integrated pest management programs (Hislop and Prokopy, 1981).

The 'Empire' apple, widely planted in Ontario, is noted for its moderate fruit size and the difficulty in thinning older trees (Forshey, 1990). Recently, the cytokinin 6-benzyladenine (BA) has been reported to have thinning activity on apple (Bound et al., 1991; Byers and Carbaugh, 1991; Elfving, 1989: Greene and Autio, 1989; Greene et al., 1990). The trials reported here evaluated thinning effects of BA alone or combined with gibberellins A_{4+7} (Promalin, PR) in comparison to NAA and CB on mature 'Empire' apple trees.

Materials and Methods

Four field trials were conducted between 1988 and 1990 at the Horticultural Experiment Station, Simcoe, Ont., Canada. All trials used single, whole-tree plots in randomized complete-block designs. All thinner treatments were applied to mature 'Empire'/ M.26 trees as dilute sprays to runoff with a hydraulic, handgun sprayer. Total blossom clusters, fruit set after June drop, shoot growth, and return bloom the following spring were determined on a single representative limb per tree (Forshey and Elfving, 1979). Limb circumference was measured at a predetermined location at bloom, again when shoot growth was measured in late August, and again the following spring. Trunk circumference was measured each year following leaf drop at a pre-marked 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. Fruit length and diameter were measured on a 25-fruit sample from each tree by laying the apples end-to-end and side-by-side in a "V"-shaped trough and measuring total length and diameter. Each fruit was sectioned equatorially to count normally developed seeds.

Midshoot leaves from current-season shoot growth were collected each August and processed for foliar analysis according to the methods of Bodnar et al. (1983).

BA vs. NAA (Expt. 1; 1988). Each of the following seven treatments was applied to a separate set of five replicate, g-year-old trees: 1) control (no treatment); 2) BA at 50, 100, or 150 mg active ingredient (a.i.)/liter; or 3) NAA at 5, 10, or 15 mg a.i./liter. Treatments were applied on 1 June (13 days after full bloom, DAFB), when fruit diameter averaged 11.0 ± 1.1 mm. Trees were spaced 3.7 × 5.5 m on a well-drained Bookton soil consisting of 40 to 100 cm of sandy sediments over glaciolacustrine clays (Hohner and Presant, 1989).

BA and NAA (Expt. 2; 1988). Each of 12 treatments was applied in a factorial treatment arrangement to a separate set of five replicate, g-year-old trees. Each treatment consisted of a tank-mix of a single concentration of the following two growth regulators: 1) BA at 0, 50, 100, or 150 mg a.i./liter; and 2) NAA at 0, 5, or 10 mg a.i./ liter. The control (BA 0 + NAA 0) was untreated. The treatments were applied on 4 June (16 DAFB) when fruit diameter averaged 11.6 ± 1.6 mm. Trees were spaced 3.7 × 5.5 m on a moderately well-drained Brantford soil consisting of 15 to 40 cm of loamy sediments over glaciolacustrine clays (Hohner and Presant, 1989).

BA, NAA, and CB (Expt. 3; 1989). The following seven treatments were each applied to five replicate, 9-year-old trees: 1) control (no treatment); 2) BA at 50 or 100 mg a.i./liter; 3) NAA at 5 or 10 mg a.i./liter; or 4) CB at 500 or 1000 mg a.i./liter. Treatments were applied on 6 June (13 DAFB), when fruit diameter averaged 9.8 ± 1.2 mm. Trees were spaced 3.7 × 5.5 m on a well-drained Brant soil consisting of a mixture of glaciolacustrine loams, silts, and fine sandy loam (Hohner and Presant, 1989).

BA and PR vs. application timing (Expt. 4; 1990). In addition to

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a single control (untreated), each of the following four treatments was applied on each of three different dates to separate sets of six replicate, 9-year-old trees: 1) BA 75 or 150 mg a.i./liter, or 2) PR 75 or 150 mg a.i./liter. BA and PR treatments were applied on 15 May (6 DAFB, mean fruit diameter 3.6 ± 0.9 mm), 29 May (20 DAFB, mean fruit diameter 10.2 ± 2.4 mm), or 7 June (29 DAFB, mean fruit diameter 17.1 ± 3.9 mm). Trees were spaced 3.7 × 5.5 m on a well-drained Wattford soil consisting of mixed glaciolacustrine sands (Hohner and Presant, 1989).

Data from Expts. 1, 3, and 4 were analyzed using a radiating regression model described by Cochran and Cox (1957) and Elfving and Allen (1987). Expt. 2 was analyzed by multiple regression. 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.). Quadratic and cubic regression models were analyzed where appropriate. Nonsignificant higher-order effects were incorporated into the error term of less-complex models, which were then reanalyzed.

Results

Experiment 1. Flowering at the start of the trial was uniform among treatments, averaging 14.0 blossom clusters/cm^2 of limb cross-sectional area (PCLA; data not shown). Fruit set and number of fruit per tree were reduced linearly in response to increased concentrations of both thinners, but were affected more strongly by BA (Table 1). Yield per tree was reduced similarly by both materials. Both fruit length and diameter were increased by BA, whereas NAA had no effect. Neither length : diameter (L:D) ratio (average value 0.86) nor number of seeds per fruit (average value 6.2) was affected by either thinner (data not shown). In 1989, return bloom was increased linearly by BA; NAA had no effect on 1989 bloom.

Fruit load at harvest was decreased linearly by both BA and NAA, but BA had a stronger thinning effect (Fig. 1). Mean fruit weight increased as fruit load was decreased, but BA treatment stimulated a much larger increase in mean fruit weight.

Numbers of shoots and shoot length were unaffected by thinners, but mean shoot length was slightly reduced by NAA (data not shown). NAA increased foliar N concentration and decreased foliar Mg (Table 1). Foliar K was increased and Ca and Mg levels were decreased by BA treatments. Initial trunk cross-sectional area (TCSA) was uniform among treatments, averaging 74.9 cm^2/tree. Final TCSA was not influenced by thinner treatments (data not shown).

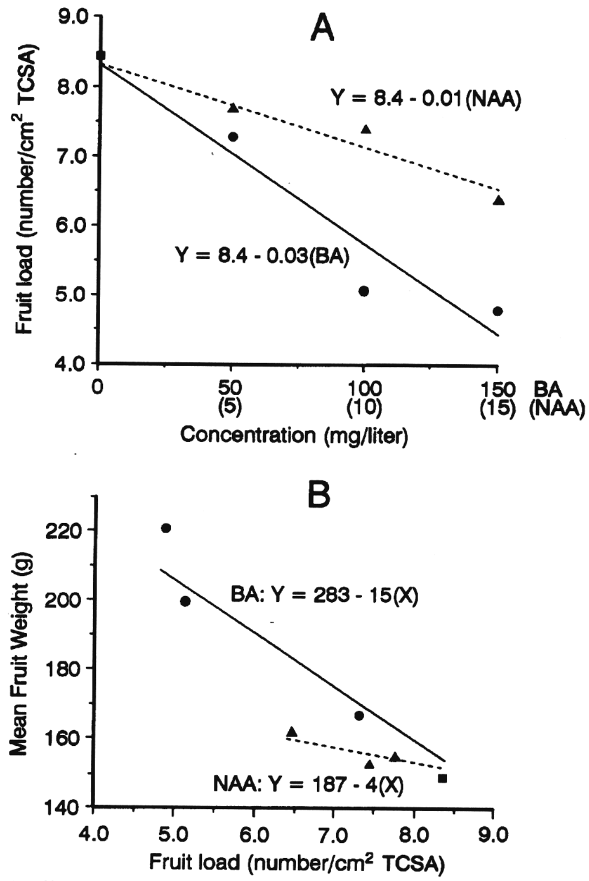

Fig. 1. Effects of BA and NAA applications on final fruit load (**A**) and relationships of fruit load to mean fruit weight (**B**) of 'Empire' apple trees (Expt. 1). Radiating regression model r^2 values: A = 0.53; B = 0.85.

Table 1. Effects of BA and NAA applications on flowering, fruit set, yield, fruit characteristics, return bloom, and foliar nutrient status of 'Empire'/M.26 trees (Expt. 1).

Treatment[z] (mg·liter^{-1})	Fruit PCLA[y]	Per tree: No. fruit	Per tree: Yield (kg)	Fruit length (cm)	Fruit diam. (cm)	1989 Blossom clusters PCLA[y]	Foliar macronutrients (%): N	K	Ca	Mg
Control	7.1	725	107	6.1	7.1	0.9	2.39	1.13	1.00	0.29
BA 50	5.9	684	114	6.4	7.4	1.9	2.47	1.05	0.99	0.30
BA 100	2.9	385	77	6.9	7.9	5.1	2.48	1.24	0.92	0.28
BA 150	3.4	432	95	6.9	8.0	5.0	2.46	1.22	0.96	0.28
NAA 5	5.7	682	106	6.2	7.2	3.4	2.51	0.85	1.11	0.31
NAA 10	7.2	627	96	6.2	7.2	1.0	2.57	1.10	1.03	0.29
NAA 15	4.3	523	85	6.3	7.4	2.7	2.61	1.19	0.91	0.28
Significance[x]										
Concentration	****	**	*	****	****	*	*	*	*	*
GR × concentration	**	*	NS	****	****	*	*	NS	NS	NS
BA	L***	L***	L*	L****	L****	L*	NS	L*	L*	L*
NAA	L*	L*	L*	NS	NS	NS	L*	NS	NS	L*

[z]Each mean contains five observations.
[y]PCLA = per square centimeter of limb cross-sectional area.
[x]L = linear effect by radiating-regression analysis. Curvilinear effects not significant ($P \leq 0.05$).
[NS, *, **, ***, ****]Effect not significant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively.

Table 2. Effects of BA and NAA applications on flowering, fruit set, yield, return bloom, and fruit characteristics of 'Empire'/M.26 trees (Expt. 2).

Treatment[z] (mg·liter^{-1})	Fruit PCLA[y]	Per tree Fruit	Per tree Yield (kg)	Mean fruit wt (g)	Fruit length (cm)	Fruit diam. (cm)	1989 Blossom clusters PCLA[y]
BA 0	8.0	612	90	150	6.4	7.1	2.6
BA 50	6.5	574	98	170	6.6	7.4	3.5
BA 100	5.6	366	69	190	6.9	7.6	7.5
BA 150	4.1	335	67	210	7.0	7.9	6.9
NAA 0	7.2	540	90	170	6.6	7.3	3.3
NAA 5	6.1	468	81	180	6.8	7.6	5.1
NAA 10	4.9	408	72	180	6.8	7.6	7.1
Significance[x]							
BA							
L	****	****	****	****	****	****	***
Q	NS	NS	NS	NS	NS	NS	NS
NAA							
L	***	***	**	**	NS	*	**
Q	NS	NS	NS	NS	NS	*	NS
BA × NAA	NS	NS	NS	NS	NS	NS	NS

[z]BA 0 + NAA 0 treatment was untreated. Each main-effects BA mean contains 15 observations. Each main-effects NAA mean contains 20 observations.
[y]PCLA = per square centimeter of limb cross-sectional area.
[x]L = linear effect, Q = quadratic effect by multiple regression analysis. Higher-order simple and interactive effects not significant ($P \le 0.05$).
NS, *, **, ***, ****Effect not significant or significant at $P \le 0.05$, 0.01, 0.001, or 0.0001.

Experiment 2. Flowering was uniform at the start of the trial, averaging 12.1 blossom clusters PCLA (data not shown). Fruit set, number of fruit, and yield per tree were decreased, and mean fruit weight and 1989 return bloom were increased in proportion to concentrations of both materials (Table 2). Fruit length and diameter were increased by BA, while NAA increased fruit diameter but not length. Neither L:D ratio (average 0.90) nor number of seeds per fruit (average 5.4) was affected by the treatments (data not shown).

Shoot growth was not altered by NAA. BA had no effect on numbers of shoots, but increased mean shoot length slightly at higher concentrations (data not shown). Initial TCSA was uniform among treatments, averaging 62.8 cm^2/tree. There was no effect of either thinner on final TCSA (data not shown). Foliar analyses were not conducted in this trial.

Experiment 3. Flowering was uniform at the start of the trial, averaging 11.1 blossom clusters PCLA (data not shown). Fruit set was reduced by BA and CB, but not NAA (Table 3). Number of fruit per tree was reduced to a different degree by all three thinners, but yield was reduced only by CB. BA, NAA, and CB produced the greatest, intermediate, and the smallest mean fruit weight, respectively. Return bloom was increased to a similar extent by all three thinners.

Shoot growth was not affected by NAA and CB, and only to a minor extent by BA (data not shown). Foliar levels of N were not influenced by thinner treatments (Table 3). Foliar K was increased by BA and CB, but not NAA. Foliar Ca was decreased by CB, while foliar Mg was reduced by all thinners, with a curvilinear response to BA and CB. Initial TCSA averaged 62.9 cm^2/tree. Final TCSA was not affected by thinner treatments (data not shown).

Table 3. Effects of BA, CB, or NAA applications on flowering, fruit set, yield, return bloom, and foliar nutrient status of 'Empire'/M. 26 trees (Expt. 3).

Treatment[z] (mg·liter^{-1})	Fruit PCLA[y]	Per tree No. fruit	Per tree Yield (kg)	Mean fruit wt (g)	1990 Blossom clusters PCLA[y]	Foliar macronutrients (%) N	K	Ca	Mg
Control	9.2	980	114	120	7.5	2.64	1.27	0.97	0.30
BA 50	9.2	615	91	150	13.8	2.71	1.37	0.82	0.30
BA 100	5.4	501	87	170	13.3	2.73	1.58	0.85	0.25
CB 500	7.1	526	78	150	15.6	2.55	1.64	0.70	0.26
CB 1000	5.5	585	86	150	14.2	2.52	1.44	0.70	0.28
NAA 5	9.9	733	97	130	12.9	2.78	1.44	1.03	0.27
NAA 10	9.3	675	90	140	17.7	2.53	1.41	1.09	0.28
Significance[x]									
Concentration	*	***	*	****	**	NS	**	NS	*
GR × concentration	*	NS	NS	****	NS	NS	NS	**	NS
BA	L*	L**	NS	L***	L*	NS	L*	NS	L*,Q*
CB	L**	L**,Q*	L*	L****,Q**	L*,Q*	NS	L****,Q****	L*	L*,Q*
NAA	NS	L*	NS	L*	L**	NS	NS	NS	L*

[z]Each mean contains five observations.
[y]PCLA = per square centimeter of limb cross-sectional area.
[x]L = linear effect, Q = quadratic effect by radiating regression analysis. GR = growth regulator.
NS, *, **, ***, ****Effect not significant or significant at $P \le 0.05$, 0.01, 0.001, or 0.0001, respectively.

Table 4. Effects of BA or BA + GA_{4+7} applications on fruit set, yield, and return bloom of 'Empire' trees (Expt. 4).

Treatment[z] (mg·liter^{-1})	Fruit PCLA[y]	Per tree No. fruit	Per tree Yield (kg)	1991 Blossom clusters PCLA[y]
Control	8.3	822	113	10.3
BA 75	8.5	586	95	15.8
BA 150	6.1	449	76	18.6
PR 75	7.5	663	101	12.2
PR 150	6.6	633	102	11.4
Significance[x]				
Concentration	**	***	**	NS
GR × concentration	NS	***	**	***
GR × timing	NS	NS	NS	NS
BA	L**	L****	L***	L**
PR	L**	L*	NS	NS

[z]Control means contain six observations; growth regulator (GR) means contain 18 observations.
[y]PCLA = per square centimeter of limb cross-sectional area.
[x]L = linear effect by radiating-regression analysis. Curvilinear effects not significant ($P \leq 0.05$).
NS,*,**,***,****Effect not significant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively.

Experiment 4. Flowering was uniform at the start of the trial, averaging 14.3 blossom clusters PCLA (data not shown). Fruit set was reduced by BA and PR to a similar extent, independent of application timing (Table 4). BA and PR reduced number of fruit per tree at all three timings, but PR had less effect. Only BA reduced yield per tree. Return bloom was stimulated by BA, but was not affected by PR.

Mean fruit weight was increased by all applications except PR at 29 DAFB (Table 5). PR only increased fruit size to the same extent as BA when applied 6 DAFB. Fruit length was increased by BA at all application timings, and by PR at 6 and 20 DAFB. Fruit diameter was increased by all applications except PR at 20 or 29 DAFB, L:D ratios were increased by all applications except BA applied 20 or 29 DAFB. The number of seeds per fruit was reduced by PR application at 20 and 29 DAFB. Foliar N was reduced by BA applied at 20 DAFB, but otherwise was not affected by thinner applications. Foliar K was increased by BA treatment at all three timings and by PR applied 6 DAFB. Foliar Ca was not influenced by any treatment, while foliar Mg was reduced only when BA or PR were applied 29 DAFB.

The number of active shoots was increased by either BA or PR applied 6 or 20 DAFB, while shoot length was increased only by applications 20 DAFB (Table 6). Mean shoot length was decreased by applications 6 DAFB, but not by later treatments. Initial TCSA averaged 61.1 cm^2/tree. Final TCSA was not affected by thinner treatments (data not shown).

Discussion

Over the concentration ranges used, BA consistently reduced 'Empire' fruit set and increased fruit weight to the same or greater extent than NAA or CB. The thinning and fruit-weight effects of

Table 5. Effects of BA or BA + GA_{4+7} applications on mean fruit weight, fruit characteristics, and foliar nutrient status of 'Empire'/M. 26 trees (Expt. 4).

Treatment[z] (mg·liter^{-1})	DAFB[y]	Mean fruit wt (g)	Fruit length (cm)	Fruit diam. (cm)	L:D ratio	Seeds/ fruit	Foliar macronutrients (%) N	K	Ca	Mg
Control	---	140	6.0	6.9	0.87	6.6	2.60	1.26	0.90	0.26
BA										
75	6	160	6.3	7.0	0.90	5.9	2.59	1.28	0.96	0.26
150	6	170	6.4	7.2	0.89	6.1	2.57	1.34	0.89	0.25
75	20	180	6.4	7.4	0.87	6.3	2.52	1.28	0.97	0.27
150	20	190	6.5	7.5	0.88	5.4	2.43	1.43	0.90	0.24
75	29	150	6.4	7.2	0.89	5.4	2.56	1.25	0.98	0.26
150	29	160	6.4	7.2	0.90	5.5	2.51	1.43	0.88	0.23
PR										
75	6	170	6.5	7.2	0.90	6.6	2.44	1.35	0.89	0.25
150	6	170	6.6	7.3	0.91	6.8	2.54	1.34	0.96	0.27
75	20	150	6.3	7.1	0.89	5.2	2.67	1.19	0.95	0.25
150	20	160	6.6	7.2	0.92	2.5	2.55	1.25	0.91	0.25
75	29	140	6.2	6.9	0.89	2.8	2.49	1.22	0.97	0.26
150	29	160	6.4	7.0	0.92	3.3	2.51	1.36	0.87	0.24
Significance[x]										
Concentration		****	****	**	***	**	NS	**	NS	*
GR × concentration		**	NS	*	***	****	NS	*	NS	NS
GR × timing		**	*	**	NS	****	NS	NS	NS	*
BA	6	L***	L***	L*	L*,Q*	NS	NS	L*	NS	NS
BA	20	L****	L****	L****	NS	NS	L*	L**	NS	NS
BA	29	L**	L***	L*	NS	NS	NS	L**	NS	L*
PR	6	L****	L****	L***	L***,Q*	NS	NS	L*	NS	NS
PR	20	L*	L****	NS	L****	L****	NS	NS	NS	NS
PR	29	NS	L**	NS	L***	L****	NS	NS	NS	L*

[z]Each mean contains six observations.
[y]DAFB = days after full bloom.
[x]L = linear effect, Q = quadratic effect by radiating-regression analysis.
NS, *,**, ***, ****Effect not significant or significant at $P \leq 0.05$, 0.01, 0.001, or 0.0001, respectively.

Table 6. Effect of BA or BA + GA_{4+7} (PR) applications on shoot growth of 'Empire'/M.26 trees (Expt. 4).

Treatment[z]		Shoot growth PCLA[y]		Mean shoot
mg·liter^{-1}	DAFB[x]	No.	Length (cm)	length (cm)
Control	---	2.8	54	19
75	6	2.4	42	18
150	6	4.1	70	17
75	20	3.2	66	20
150	20	4.5	89	19
75	29	2.5	54	22
150	29	2.5	49	20
Significance[w]				
Concentration		**	*	*
GR × concentration		NS	NS	NS
GR × timing		**	**	**
6 DAFB		L*	NS	L**
20 DAFB		L***	L**	NS
29 DAFB		NS	NS	NS

[z]Each control mean contains six observations; each concentration mean contains 12 observations.
[y]PCLA = per square centimeter of limb cross-sectional area.
[x]DAFB = days after full bloom.
[w]L = linear effect by radiating-regression analysis. Curvilinear effects not significant ($P \leq 0.05$). GR = growth regulator.
NS,*,**,***Effect not significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

BA and NAA were not influenced when they were applied together in a tank mix; each material reduced fruit set and increased fruit weight relative to its own concentration in the applied solution (Greene et al., 1990). Yield is primarily a function of fruit number (Forshey and Elfving, 1977). Thinning with BA reduced yield in three of four trials reported here. The large BA-induced fruit-weight increase was not sufficient to offset the effect of fewer fruit per tree on total yield. The increases in fruit weight associated with BA treatment suggest significant improvement in the 'fruit-size distribution in the crop, a factor that may have important economic implications for the marketing of 'Empire' apples.,

BA applied as a thinner stimulated increased shoot growth in three of four trials. BA applications at or shortly after bloom have been shown to stimulate lateral buds to form shoots (Elfving, 1984; Forshey, 1982); similar results have been observed in other trials with BA (Bound et al., 1991; Greene and Autio, 1990; Greene et al., 1990). Despite the small increase in shoot growth induced by BA, it was as or -more effective than either NAA or CB in increasing return bloom. Modest vegetative growth stimulation by BA without detrimental effects on flowering may aid the management of heavily cropping, dwarf apple trees.

Effects of all thinners on foliar nutrient concentrations primarily reflected crop load-induced changes in foliar levels of N, K, Ca, and Mg. Increased foliar K concentrations resulting from reduced fruit load may have induced lower Ca and Mg concentrations in the leaves.

PR is reported to thin some apple cultivars (Strydom and Honeyborne, 1986). In one trial reported here, PR was not as effective as BA for thinning mature 'Empire' apple trees and reduced number of seeds per fruit at two of three application timings, similar to observations by Greene et al. (1982) on 'McIntosh'. Altered seed number can affect fruit shape and may contribute to storage-related problems (Proctor and Schechter, 1992).

BA produced a thinning response in 1990 from a fruit diameter of 3.6 mm (6 DAFB) to 17 mm (29 DAFB). Bound et al. (1991) reported maximum thinning response of 'Fuji' to BA at 20 DAFB, but gave no fruit diameter data for comparison. Other workers have reported maximum sensitivity of fruitlets to thinning at around the 10- to 12-mm fruit diameter range (Knight, 1980; Leuty, 1973). In 1990, PR reduced fruit set over the same time interval as BA, but to a lesser extent.

PR had neither a positive nor negative effect on return bloom despite its thinning effect. Gibberellins, especially GA_7, are known to inhibit flower formation in apple (Looney et al., 1985; McLaughlin and Greene, 1984, 1991; Tromp, 1982). In other trials using PR, no detrimental effect on (Strydom and Honeyborne, 1986) or a reduction in (McLaughlin and Greene, 1991) return bloom has been reported. The absence of a return-bloom response in PR treatments reported here was not related to changes in shoot growth, and likely resulted from the opposing effects on flowering of BA and GA_{4+7} (McLaughlin and Greene, 1991).

In addition to its efficacy as a chemical thinner, BA poses no problem for integrated pest management programs. In recent tests, BA had little or no toxic effects on several important predatory mite species used for biological control of phytophagous mites on apple (Thistlewood and Elfving, 1992).

In the trials reported here, BA displayed the reliability in thinning typically associated with CB. Thinning responses were concentration-dependent and less variable than those of NAA, a characteristic that continues to limit interest in NAA as a thinner in many areas. BA has considerable promise as a thinner for mature 'Empire' apple trees.

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