J. AMER. SOC. HORT. SCI. 116(5):807-812. 1991.

Reduced Rates and Multiple Sprays of Paclobutrazol Control Growth and Improve Fruit Quality of 'Delicious' Apples

Duane W. Greene

Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003

Additional index words. Malus domestica, PP33, triazole, fruit calcium, growth retardation, fruit set, fruit thinning, Promalin

Abstract. **'Gardiner Delicious'/MM.lO6 apple *(Malus domestics* Borkh.) trees were initially sprayed in 1985 with paclobutrazol (PB) at 250 mg.liter^{-1} at tight cluster and again on 10 and 25 June and 29 July. From 1986 through 1988, PB sprays of 85 or 100 mg·liter^{-1} were applied at either petal fall (PF) + 2 or PF + 4 weeks and one to two additional sprays were applied per year when growth resumed. Promalin was applied to one group of trees that received PB starting at PF + 2 weeks. PB reduced terminal, lateral, and total shoot growth the year of application and in subsequent years. Although average shoot length of lateral and terminal shoots was reduced, the greatest reduction in growth occurred because PB prevented spurs from growing into lateral and terminal shoots. Compared to unsprayed trees, PB reduced pruning time in all 4 years by 23% to 70%. PB increased bloom only the first year after application, but increased fruit set for 2 years due to a carryover effect. Application of PB in 1985 caused a reduction in fruit size, sometimes in soluble solids concentration, length : diameter (L : D) ratio, and pedicel length. Promalin either overcame the reduction in the ratio or increased it in 1986. Reduced rates of PB in subsequent years caused few adverse effects on the fruit. PB increased flesh firmness when applied at PF + 2 weeks but not at PF + 4 weeks. Trees treated with PB produced fruit with higher flesh Ca and less bitter pit, cork spot, and senescent breakdown following regular air storage. Chemical names used: ß -(4 -chlorophenyl)methyl -α- 1,1-dimethylethyl) -1H-l,2,4-triazole-1-ethanol (paclobutrazol, PB); gibberellins A_{4+7} plus N-(phenylmethyl) -1H-purine-6-amine (Promalin).**

Control of apple tree vigor has become more important as trees are planted at higher densities and as labor required for more intensive management becomes increasingly expensive and difficult to obtain. Excessive tree vigor can reduce flower bud formation, fruit set, and result in reduced fruit quality. The vigor of cultivars, such as nonspur 'Delicious' on vigorous rootstock, is particularly difficult to control.

PB is one of several steroid-inhibiting compounds that can retard tree growth (Curry et al., 1989; Williams et al., 1986). PB was used successfully to retard growth of apple trees (Elfving and Proctor, 1986; Greene, 1986; Miller and Swietlik, 1986; Richardson et al., 1986; Volz and Knight, 1986). However, concentrations of PB used for growth control frequently cause undesirable effects, such as reduced fruit size (Elfving and Proctor, 1986; Greene, 1986; Milieu and Sfakiotakis, 1986; Prive et al., 1989), decreased L : D ratio (Curry and Williams, 1983; Elfving et al., 1987; El-Khoreiby et al., 1990; Greene, 1986; Jones et al., 1988), reduced pedicel length (Curry and Williams, 1983; Elfving and Proctor, 1986; Greene, 1986; Prive et al., 1989), reduced fruit soluble solids content (Curry and Williams, 1986; Elfving et al., 1990; Greene and Murray, 1983), and reduced leaf area (Church et al., 1984; Curry and Williams, 1983; Greene, 1986; Sansavini et al., 1986). PB may also cause fruit thinning (Church et al., 1984; Volz and Knight, 1986) and increase russeting (El-Khoreiby et al., 1990) if applied during the early postbloom period. Many of the undesirable effects of PB on fruit may be either reduced or eliminated if application is delayed until later in the season (El-Khoreiby et al., 1990; Lever, 1986). Applying several sprays using reduced rates of triazoles has been more successful in controlling vegetative growth than one spray at high concentration earlier in the season (Curry and Jones, 1990; Milieu and Sfakiotakis, 1986; Quinlan and Richardson, 1986).

The investigation reported here was initiated to determine if the growth of vigorous 'Delicious' apple trees could be adequately controlled, with minimal side effects on fruit, by using multiple sprays of PB at reduced rates.

Materials and Methods

A block of 35 nine-year-old 'Gardiner Delicious'/MM.lO6 trees growing at the Univ. of Massachusetts Horticultural Research Center in Belchertown were grouped into seven complete blocks (replications) of five trees each. In 1985, four trees in each block were sprayed at tight cluster (23 Apr.) and again on 10 and 25 June and 29 July with 250 mg PB/liter in 0.01% (v/v) Tween 20 (Table 1). One of the sprayed trees in each block received no further PB sprays for the duration of the experiment. The remaining three trees received three more applications of 85 mg·liter^{-1} in 1986, two applications of 100 mg·1iter^{-1} in 1987, and two applications of 85 mg·liter^{-1} in 1988. Treatments were started either 2 or 4 weeks after PF, and one tree in each block that received the first PB spray at PF + 2 weeks was sprayed with 25 mg Promalin/liter at king bloom.

Before bloom each year, two limbs per tree, each limb 10 to 15 cm in circumference, were tagged and all blossom clusters counted. After the completion of June drop in July, the number of persisting fruit on each limb was counted.

At the normal harvest time, a 30-apple sample was collected randomly from the periphery of each tree and weighed. The total length and diameter of fruit in each sample were measured and the L : D ratio calculated. The pedicels were removed from 20 randomly selected fruit and their lengths measured. Flesh firmness of 10 representative fruit was measured using a Mag-

Received for publication 20 Aug. 1990. Paper no. 2971, Massachusetts Agricultural Experiment Station, Univ. of Massachusetts at Amherst. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement solely* to indicate this fact.

Abbreviations: L D, length : diameter PB, paclobutrazol; PF, petal fall; SSC, soluble solids concentration.

Table 1. Time of application and concentration of PB sprayed on 'Gardiner Delicious' apples.

Treatments	Dates and rates (in mg·liter^{-1}) of paclobutrazol application			
	1985, 250	1986, 85	1987, 100	1988, 85
Control	---	---	---	---
PB, 1985 only	23 Apr.	---	---	---
	10 June	---	---	---
	25 June	---	---	---
	29 July	---	---	---
PB, first spray PF + 4 weeks	23 Apr.	10 June	13 June	24 June
	10 June	7 July	7 July	13 July
	25 June	12 Aug.		
	29 July			
PB, first spray PF + 2 weeks	23 Apr.	27 May	30 May	7 June
	10 June	7 July	7 July	13 July
	25 June	12 Aug.		
	29 July			
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1} at king blossom[z]	23 Apr.	27 May	30 May	7 June
	10 June	7 July	7 July	13 July
	25 June	12 Aug.		
	29 July			

[z]Promalin applied 6, 9, and 15 May in 1986, 1987, and 1988, respectively.

ness-Taylor penetrometer (11.1-mm-diameter probe; Ballauf Manufacturing Co., Laurel, Md.) by making two punctures per fruit on opposite sides. The expressed juice was collected during the firmness test, and the soluble solids concentration (SSC) was then determined from the composite sample using a hand refractometer.

A 20-kg fruit sample was collected from each tree at normal harvest and placed in regular air storage at 0C for 20 to 26 weeks. A 10-apple sample of representative fruit was harvested when the storage sample was taken and flesh Ca was determined (Weis et al., 1980). At the end of the storage period, fruit were removed and flesh firmness on a 20-apple sample was determined as described, but with one puncture per fruit. Fruit remained at room temperature (≈22C) until storage disorders started to develop (12 to 22 days). All fruit in the storage sample were assessed for senescent breakdown, bitter pit and cork spot, superficial scald, and fruit decay.

Before the first PB spray was applied in 1986 through 1988, the length of 15 randomly selected terminal shoots was measured on each tree. After leaf abscission in the fall, two limbs per tree that were 10 cm in circumference were selected, and all current-season terminal and lateral shoot growth was measured. Lateral growth was defined as shoots that originated from buds or previous-season shoots that had grown <5 cm the previous year, and terminal growth as shoots that originated from previous-season shoots that had grown 5 cm or more the previous year. In March, the time required to prune each tree was determined. In 1987, the time to remove watersprouts was measured in addition to the total pruning time.

Data were analyzed as a one-way treatment arrangement in a randomized complete-block design using analysis of variance (Statistical Package for Social Sciences, Chicago). Means were separated using Duncan's multiple range test. Arcsin transformations of percentage data were done where appropriate.

Results

Growth and pruning time. PB consistently reduced terminal growth and lateral growth during the 4 years of the experiment (Table 2). Annual applications of PB were required to consistently reduce the mean length of both lateral and terminal shoots. The time of initial PB applications had no influence on the length of terminal or lateral shoots. The number of lateral and terminal shoots was reduced by PB as a carryover effect, and further reduction was reinforced by the annual PB sprays. PB drastically reduced total shoot growth. This reduction was caused primarily by a reduction in the numbers of lateral and terminal shoots rather than the average length.

Significant retardation of terminal growth early in the season was apparently due to a carryover effect. Terminal growth at PF + 2 weeks on trees initially treated at PF + 2 weeks was reduced 30%, 45%, and 29%, respectively, in 1986 through 1988 (data not shown). Terminal growth at PF + 4 weeks on trees initially treated at PF + 4 weeks was reduced by 35%, 55%, and 37%, respectively, in 1986 through 1988 (data not shown).

Pruning times were consistently reduced by PB (Table 3). While pruning the trees in 1986, we observed that a significant amount of time was spent removing watersprouts. Removal of watersprouts was timed separately in 1987, and this revealed that a significant amount of pruning time on PB-treated trees was saved due to a lack of watersprout growth. Pruning time was reduced during all 4 years of the experiment by the initial application made in 1985. Pruning time was further reduced in general by annual applications of PB.

Bloom and fruit set. Control trees and trees treated only in 1985 had uniform bloom before the initiation of PB applications (Table 4). In general, PB treatments had little influence on bloom, except in 1986 when all PB treatments had more bloom than the control. PB application at tight cluster and subsequent sprays, starting at PF + 4 weeks, did not influence fruit set the year of initial application. PB increased fruit set as a carryover effect in 1986 and 1987. When first applied at PF + 2 weeks, PB reduced fruit set to the control level in 1986 and 1987. When the initial application of PB was delayed to PF + 4 weeks, fruit set was not reduced. Promalin reduced fruit set relative to PB in 2 of the 3 years, but in only 1 year was set reduced below the level of control trees. Compared to the control, PB application in 1985 increased yield in 1986 and 1987, but reduced

Table 2. Effects of PB applied in 1985 through 1988 on vegetative growth of 'Gardiner Delicious' apples.[z,y]

Treatment	No./cm limb circumf.				Mean length (cm)				Length/cm limb circumf.			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
Lateral shoots												
Control	3.3 a	2.0 a	3.8 a	1.7 a	23.2 a	20.2 a	16.9 a	16.2 a	75.5 a	40.4 a	64.1 a	27.0 a
PB, 1985 only	1.7 b	0.5 b	1.7 b	1.2 ab	14.4 b	22.0 a	16.1 a	13.0 ab	24.1 b	11.8 b	26.6 b	15.9 b
PB, first spray PF + 4 weeks	---	0.5 b	0.9 c	0.3 d	---	13.4 b	10.3 b	12.7 b	---	6.7 b	12.0 c	4.5 c
PB, first spray PF + 2 weeks	---	0.3 b	0.4 c	1.0 bc	---	11.7 b	10.9 b	13.6 ab	---	4.6 b	4.7 c	14.3 b
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	0.5 b	0.9 c	0.7 cd	---	13.4 b	13.1 ab	15.9 ab	---	7.6 b	11.5 c	10.5 bc
Terminal growth												
Control	1.0 a	1.0 a	0.7 a	2.0 a	47.7 a	37.0 a	36.0 b	34.4 ab	46.7 a	35.7 a	25.5 a	45.5 a
PB, 1985 only	1.2 a	0.8 ab	0.5 b	1.1 b	26.4 b	34.9 ab	42.7 a	36.6 a	29.3 b	26.0 b	22.5 ab	28.3 b
PB, first spray PF + 4 weeks	---	0.8 ab	0.4 bc	0.6 c	---	20.1 c	21.8 c	26.5 b	---	15.6 c	9.8 cd	10.9 d
PB, first spray PF + 2 weeks	---	0.7 ab	0.3 c	0.6 c	---	21.1 c	24.7 c	39.6 a	---	13.9 c	7.9 d	14.5 cd
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	0.7 b	0.4 bc	0.7 bc	---	24.8 bc	34.2 b	43.1 a	---	16.8 c	15.7 bc	22.6 bc

[z]Mean separation in columns by Duncan's new multiple range test ($P = 0.05$).
[y]Means of 14 observations.

Table 3. Effects of PB applied 1985 through 1988 on pruning time in March of 'Gardiner Delicious' apples.[z,y]

Treatment	Pruning time (min/tree)				Watersprouts
	1986	1987	1988	1989	1987
Control	17.3 a	12.0 a	21.0 a	22.2 a	9.0 a
PB, 1985 only	9.1 b	6.4 b	12.7 b	16.3 b	4.5 b
PB, first spray PF + 4 weeks	---	4.0 c	6.9 c	7.8 c	1.8 c
PB, first spray PF + 2 weeks	---	4.4 c	6.4 c	12.8 b	1.7 c
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	4.1 c	7.1 c	13.0 b	1.7 c

[z]Mean separation in columns by Duncan's new multiple range test ($P = 0.05$).
[y]Means of seven observations.

Table 4. Effects of paclobutrazol applied 1985 through 1988 on bloom and fruit set of 'Gardiner Delicious' apples.[z,y]

Treatment	Blossom clusters/cm limb circumf.				Fruit/cm limb circumf.				Yield (kg/tree)			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
Control	10.3 a	8.9 b	12.1 a	13.6 a	5.8a	5.7 b	4.0 b	5.3 ab	78 a	114 b	152 ab	194 a
PB, 1985 only	10.2 a	12.8 a	15.2 a	10.3 b	4.6 a	8.4 a	7.7 a	5.3 ab	76 a	182 a	194 a	140 c
PB, first spray PF + 4 weeks	---	13.1 a	15.4 a	13.3 a	---	6.4 ab	7.2 a	5.1 ab	---	150 a	160 ab	146 bc
PB, first spray PF + 2 weeks	---	12.7 a	15.3 a	14.0 a	---	5.4 b	3.9 a	6.6 a	---	76 bc	124 b	184 ab
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	13.2 a	14.0 a	14.5 a	---	1.5 c	3.3 b	4.8 b	---	46 c	108 b	166 abc

[z]Means of 14 observations.
[y]Mean separation Duncan's new multiple range test ($P = 0.05$).

yield in *1988*. Each year, yields of trees treated with PB at PF + 4 weeks were similar to those of trees treated only in 1985.

Fruit quality. PB reduced weight per fruit the year of application (Table 5). This weight was also reduced on trees treated at PF + 4 weeks, but not on trees treated at PF + 2 weeks. Because PB increased fruit set in most situations where fruit size was reduced, the reduction may have been due to a direct effect of the chemical, an indirect effect due to crop load, or a combination of both. All PB treatments increased flesh firmness the year of application in 1985 and 1986. Firmness was increased in 1987 only when PB was first applied at PF + 2 weeks, and in 1988, no treatment increased flesh firmness. There was no carryover effect of PB on flesh firmness and no consistent effect on SSC. PB reduced fruit L : D ratio and pedicel length the first 2 years of the experiment, whereas there was either a diminished effect or no effect at all for the last 2 years (Table 6). Promalin application increased the L: D ratio of PB-treated fruit above that of the control fruit, but it increased pedicel length only 1 year.

Storage potential. Following storage, fruit from trees treated

Table 5. Effects of PB applied 1985 through 1988 on fruit quality at harvest of 'Gardiner Delicious' apples.[z]

Treatment	Fruit wt (g)[y]				Flesh firmness (N)[x]				SSC (%)[y]			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
Control	172 a	163 ab	187 a	154 b	82.1 b	80.7 d	89.9 bc	82.1 a	11.5 a	12.2 a	12.3 a	10.3 b
PB, 1985 only	148 b	152 c	170 b	164 a	86.7 a	81.6 cd	87.6 c	81.6 a	11.3 a	11.2 b	11.6 b	10.3 b
PB, first spray PF + 4 weeks	---	147 c	159 b	159 b	---	83.9 bc	89.0 c	81.6 a	---	11.6 ab	11.4 b	10.6 a
PB, first spray PF + 2 weeks	---	154 bc	180 a	154 b	---	86.2 ab	92.2 a	81.2 a	---	11.8 ab	11.4 b	10.0 b
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	165 a	181 a	155 b	---	86.7 a	95.4 a	81.6 a	---	12.2 a	11.9 ab	10.3 b

[z]Mean separation in columns by Duncan's new multiple range test ($P = 0.05$).
[y]Means of seven observations.
[x]Means of 140 observations.

Table 6. Effect of PB applied 1985 through 1988 on fruit shape of 'Gardiner Delicious' apples at harvest.[z]

Treatment	L : D ratio[y]				Pedicel length (cm)[x]			
	1985	1986	1987	1988	1985	1986	1987	1988
Control	0.88 a	0.93 b	0.88 b	0.93 b	3.4 a	3.2 a	2.2 ab	2.8 a
PB, 1985 only	0.81 b	0.91 c	0.88 b	0.92 b	1.9 b	2.7 bc	2.3 a	2.6 bc
PB, first spray PF + 4 weeks	---	0.89 cd	0.92 b	0.92 b	---	2.6 bc	2.1 b	2.4 c
PB, first spray PF + 2 weeks	---	0.88 d	0.91 b	0.92 b	---	2.6 c	2.2 ab	2.6 ab
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	0.99 a	0.96 a	0.96 a	---	2.9 b	2.2 ab	2.8 a

[z]Mean separation in columns by Duncan's new multiple range test ($P = 0.05$).
[y]Means of seven observations.
[x]Means of 140 observations.

in 1985 and 1986 were firmer than fruit treated only in 1985 or control fruit (Table 7). Only fruit initially sprayed at PF + 2 weeks were firmer than controls in 1987, and in 1988, all fruit were similarly firm. In most cases, flesh of fruit from PB-treated trees contained more Ca than that of control fruit. There was some carryover effect of PB on Ca, since fruit from trees treated only in 1985 had higher Ca content 2 years later. Compared to control fruit, fruit from PB-treated trees generally had less senescent breakdown and decay during the first 3 years following storage, while bitter pit and cork spot were reduced by all treatments only in 1985 and 1986 (Table 8). Fruit from treated and control trees stored similarly well during the 4th year of the experiment.

Discussion

There were several beneficial effects that would make the application of PB or a similar growth retardant to apple trees useful on a routine basis. Pruning is a major production cost. Compared to the control, pruning time was reduced by 23% to 70% for PB-treated trees. The number of shoots was reduced, transforming trees into a more desirable, spur-type growth habit. Fruit flesh Ca was increased, as was postharvest storage life of the fruit treated by PB. PB did have undesirable effects, including reduced pedicel length, fruit size, L : D ratio, and, sometimes, SSC. Promalin was included as one of the treatments in this investigation because it can reverse the undesirable effects of PB on L : D ratio and pedicel length (Curry and Williams, 1983). PB reduced the L : D ratio only in 1986, and Promalin not only reversed that effect but also increased the L : D above that of the control. Promalin did not overcome the reduction by PB of pedicel length, which maybe more long-lived and more difficult to reverse (Greene, 1986; Prive et al., 1989). The lack of response maybe due in part to the application of Promalin at bloom, when much of the pedicel growth has already occurred (Prive et al., 1989).

Shoot growth is most rapid soon after bloom. Therefore, it is generally believed growth retardants must be applied soon after bloom to achieve appropriate and significant growth con-

Table 7. Effects of PB applied in 1985 through 1988 on fruit Ca at harvest and flesh firmness following air storage of 'Gardiner Delicious' apples.[z]

Treatment	Flesh firmness[y] (N)				Fruit Ca[x] (mg·g^{-1})			
	1985	1986	1987	1988	1985	1986	1987	1988
Control	59.6 b	54.6 cd	67.0 b	50.0 ab	---	179 b	124 c	221 b
PB, 1985 only	66.0 a	52.7 d	66.0 b	49.5 b	---	210 a	138 b	214 b
PB, first spray PF + 4 weeks	---	56.9 b	58.3 b	50.9 ab	---	228 a	161 a	233 ab
PB, first spray PF + 2 weeks	---	58.7 ab	72.5 a	50.9 ab	---	214 a	168 a	237 a
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	59.6 a	72.0 a	52.3 a	---	210 a	159 a	249 a

[z]Mean separation in columns by Duncan's new multiple range test ($P = 0.05$).
[y]Means of 140 observations.
[x]Means of seven observations.

Table 8. Effect of PB applied in 1985 through 1988 on storage disorders following air storage of 'Gardiner Delicious' apples.[z,y]

Treatment	Senescent breakdown (%)				Bitter pit and cork spot (%)				Decay (%)			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
Control	1.9 a	4.5 a	7.0 a	0.9 a	7.6 a	1.4 a	3.2 a	2.8 ab	1.8 a	4.3 a	17.1 a	4.8 a
PB, 1985 only	0.1 b	0.3 b	3.0 b	1.3 a	1.7 b	0.6 b	2.7 ab	3.9 a	0.8 a	0.6 b	6.0 b	4.0 a
PB, first spray PF + 4 weeks	---	0.5 b	2.2 b	0.9 a	---	0.2 b	1.1 ab	1.8 b	---	0.8 b	6.0 b	4.5 a
PB, first spray PF + 2 weeks	---	0.8 b	1.7 b	1.0 a	---	0.0 b	0.6 b	2.0 ab	---	1.2 b	6.4 b	4.0 a
PB, first spray PF + 2 weeks + Promalin, 25 mg·liter^{-1}	---	1.4 b	3.2 b	1.7 a	---	0.3 b	2.2 ab	1.3 b	---	1.4 b	9.1 b	4.8 a

[z]Mean separation by Duncan's new multiple range test ($P = 0.05$).
[y]Means of seven observations.

trol. In this investigation, PB reduced early terminal growth as a carryover effect, producing no advantage from starting treatments as early as PF + 2 weeks. Growth retardation was either similar or better when the initial spray was applied at PF + 4 weeks.

The growth retardation effect of PB is frequently documented using terminal growth reduction (Church et al., 1984; Miller and Swietlik, 1986; Milieu and Sfakiotakis, 1986; Richardson et al., 1986; Sansavini et al., 1986; Volz and Knight, 1986; Williams et al., 1986). Terminal growth was reduced in this investigation. However, the most important vegetative response was a large reduction in the number of spurs that grew into lateral shoots and the number of lateral shoots that continued to grow as terminal shoots. Elfving and Proctor (1986) reported that PB reduced shoot count on 'Spartar' and 'McIntosh' as a carryover effect.

PB may increase flowering in apple (Jones et al., 1988; Sansavini et al., 1986; Volz and Knight, 1986), or have no effect (Greene, 1986). Return bloom in this investigation was increased only in 1986. The lack of response in other years may be attributed to an increase in fruit set. Although PB may inhibit gibberellin biosynthesis (Hedden and Graebe, 1985), which is known to reduce flowering, the mobility and redistribution of PB in the tree is very limited (Quinlan and Richardson, 1986). Most likely, insufficient PB was translocated to the seeds, which is the primary source of gibberellins that inhibit flowering in a bearing tree.

In 2 of the 4 years (1986 and 1987), PB reduced crop load below the level of trees receiving PB only in 1985, when the first application was made at PF + 2 weeks. When the initial application was delayed an additional 2 weeks, to PF + 4 weeks, no thinning occurred. This result is in agreement with earlier observations that PB can reduce fruit set when applied from full bloom (Church et al., 1984) up to 3.5 weeks after full bloom (Richardson et al., 1986; Volz and Knight, 1986). There have been several reports where PB did not thin apples (Greene, 1986; Jones et al., 1988; Stinchcombe et al., 1984). I do not know if the absence of thinning in these cases was due to an inconsistent thinning potential of PB, application at a time when fruit were less sensitive to chemical thinners, or the inability of PB to thin under some environmental conditions. Additionally, the thinning response to PB applications may be cultivar-dependent (Volz and Knight, 1986).

PB increased the storage life of fruits in this investigation by reducing senescent breakdown, decay, and bitter pit and cork spot. This result confirms earlier reports of the positive effect of PB on postharvest life of apples (Elfving et al., 1987; Greene, 1986). PB also increased fruit flesh Ca for the 3 years it was measured. Calcium plays an important role in determining the storage potential of fruit (Bramlage et al., 1979). Increased Ca cannot be attributed to a reduction in fruit size, since trees treated with PB. starting at PF + 2 weeks had similar fruit set and size each year but higher fruit Ca. Actively growing shoots compete with fruit for Ca. Therefore, Ca levels in fruit from PB-treated trees may have been increased indirectly by reducing vegetative growth and reducing competition for Ca. PB decreased Ca uptake in apple seedlings growing in nutrient solution (Swietlik and Miller, 1984); however, Ca concentration in the leaves and stems was increased (Swietlik and Miller, 1985). They suggested Ca uptake was decreased less than dry matter accumulation, thus effectively increasing Ca concentration in the leaves and shoots.

Literature Cited

Bramlage, W. J., M. Drake, and J.H. Baker. 1979. Changes in calcium levels in apple cortex tissue shortly before harvest and during postharvest storage. Commun. Soil Sci. 10:417-426.

Church, R. M., L. Copas, and R.R. Williams. 1984. Changes in fruit set, leaf size, and shoot growth of apple caused by some fungicides, insecticides, and a plant growth regulator. J. Hort. Sci. 59:161-164.

Curry, E.A. and K.M. Jones. 1990. Controlling growth of 'Delicious' apple trees with low-dosage applications of uniconizole or BAS111. J. Hort. Sci. 65:619-626.

Curry, E. A., A.N. Reed, and M.W. Williams. 1989. Transitory control of vegetative growth of pome and stone fruit trees with less persistent triazole derivatives. Acta Hort. 239:229-233.

Curry, E.A. and M.W. Williams. 1983. Promalin of GA_3 increase pedicel and fruit length and leaf size of 'Delicious' apple treated with paclobutrazol. HortScience 18:214-215.

Curry, E.A. and M.W. Williams. 1986. Effect of paclobutrazol on fruit quality: Apple, pear and cherry. Acta Hort. 179:743-753.

Elfving, D. C., C.L. Chu, E.C. Lougheed, and R.A Cline. 1987. Effects of daminozide and paclobutrazol treatments on fruit ripening, and storage behavior of 'McIntosh' apple. 1987. J. Amer. Soc. Hort. Sci. 112:910-915.

Elfving, D.C. and J.T.A. Proctor. 1986. Long-term effects of paclobutrazol (Cultar) on apple-tree shoot growth, cropping, and fruit-leaf relations. Acta Hort. 179:473-480.

Elfving, D. C., E.C. Lougheed, C.L. Chu, and R.A. Cline. 1990. Effect of daminozide, paclobutrazol, and uniconazole treatments on 'McIntosh' apples at harvest and following storage. J. Amer. Soc. Hort. Sci. 115:750-756.

El-Khoreiby, A. M., C.R. Unrath, and L.J. Lehman. 1990. Paclobutrazol spray timing influences apple tree growth. HortScience 25:310-312.

Greene, D.W. 1986. Effect of paclobutrazol and analogs on growth, yield, and fruit quality, and storage potential of 'Delicious' apples. J. Amer. Soc. Hort. Sci. 111:328-332.

Greene, D.W. and J. Murray. 1983. Effect of paclobutrazol (PP333) and analogs on growth, fruit quality and storage potential of 'Delicious' apples. Proc. Plant Growth Regulat. Soc. Amer. 10:207-212.

Hedden, P. and J.E. Graebe. 1985. Inhibition of gibberellin biosyn-

thesis by paclobutrazol in cell-free homogenates of *Cucurbita maxima* endosperm and *Malus pumila* embryos. J. Plant Growth Regulat. 4:111-112.

Jones, K. M., P. Jotic, T.B. Keen, S.B. Longley, and G. Adams. 1988. Restructuring and cropping large 'Red Delicious' apple trees with paclobutrazol and daminozide. J. Hort. Sci. 63:19:25.

Lever, B. 1986. Cultar–A technical overview. Acta Hort. 179:459-466.

Milieu, P.G. and E. M. Sfakiotakis. 1986. Growth retardation activity of paclobutrazol on Delicious apples. Acta Hort. 179:551-552.

Miller, S.S. and D. Swietlik. 1986. Growth and fruiting response of deciduous fruit trees treated with paclobutrazol. Acta Hort. 179:563-566.

Prive, J. P., D.C. Elfving, and J.T.A. Proctor. 1989. Paclobutrazol, gibberellin,, and cytokinin effects on growth, development, and histology of apple pedicels and fruit. J. Amer. Soc. Hort. Sci. 114:273–278.

Quinlan, J.D. and P.J. Richardson. 1986. Uptake and translocation of paclobutrazol and implications for orchard use. Acta Hort. 179:443-451.

Richardson, P. J., A.D. Webster, and J.D. Quinlan. 1986. The effect of paclobutrazol sprays with or without the addition of surfactants on the shoot growth, yield and fruit quality of the apple cultivars Cox and Suntan. J. Hort. Sci. 61:439-446.

Sansavini, S., R. Bonomo, A. Finotti, and V. Palara. 1986. Foliar and soil application of paclobutrazol on Gloster apple. Acta Hort. 179:489-496.

Stinchcombe, G. R., E. Copas, R.R. Williams, and G. Arnold. 1984. The effects of paclobutrazol and daminozide on the growth and yield of cider apple trees. J. Hort. Sci. 59:323-327.

Swietlik, D. and S. S. Miller. 1984. The effect of paclobutrazol on the growth and uptake of Ca and K by apple seedlings. J. Plant Nutr. 7:1555-1565.

Swietlik, D. and S.S. Miller. 1985. The effect of paclobutrazol on mineral nutrition of apple seedlings. J. Plant Nutr. 8:369–382.

Volz, R.K. and J.N. Knight. 1986. The use of growth regulators to increase precocity in apple trees. J. Hort. Sci. 61:181-189.

Weis, S. A., M. Drake, W.J. Bramlage, and J.H. Baker. 1980. A sensitive method for measuring changes in calcium concentration in 'McIntosh' apples demonstrated in determining effects on foliar calcium sprays. J. Amer. Soc. Hort. Sci. 105:346-349.

Williams, M. W., E.A. Curry, and G.M. Greene. 1986. Chemical control of vegetative growth of pome and stone fruit trees with a GA biosynthesis inhibitor. Acta Hort. 179:453458.