Prohexadione-Ca: A Promising Chemical for Controlling Vegetative Growth of Apples

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Managing growth of apple (*Malus ×domestica* Borkh.) trees is an ongoing concern for orchardists. Reducing growth of young trees to hasten flowering and fruiting, containment of bearing trees to their allocated space to prevent crowding and excessive shading, and controlling vegetative growth in crop loss years are all challenges to apple growers. Historically, the most successful commercial strategy for controlling vegetative growth has been the use of Alar® (daminozide; 2,2 dimethylhydrazide) alone or tank-mixed with ethephon (2-chloroethyl phosphonic acid). With the withdrawal of the Alar label, effective vegetative growth control options for apples were essentially eliminated.

A new class of growth retardants, the acylcyclohexanediones, are now available (Rademacher et al., 1992). Their mode of action is the inhibition of either 2 β -hydroxylase (Griggs et al., 1991) or 3 β -hydroxylase (Nakayama et al., 1992), which blocks gibberellin synthesis. One of these chemicals, prohexadione-Ca (BAS-125, or Apogee®) is being extensively researched. Nakayama et al. (1990) reported that prohexadione-Ca (PHD-Ca) retarded shoot elongation in rice, and that the reduction in elongation was directly related to inhibition of gibberellin biosynthesis (Nakayama et al., 1992). This compound is currently being evaluated for its effects on many different crops. This research reports on the response of apples to PHD-Ca under orchard conditions.

MATERIALS AND METHODS

The growth regulator was applied with a three-point hitch airblast sprayer with a 32-inch (81.3 cm) variable pitch fan, or hand gun treatments were applied to runoff using the same sprayer from the hose bib attachment. All airblast applications were based on tree row volume (TRV) calculated dilute water requirement for pesticide application (Sutton and Unrath, 1988). All PHD-Ca solutions included 0.1% (v/v) Regulaid® (Kalo, Overland Park, Kans.) as a surfactant. Control trees were not sprayed.

A list of experiments conducted, location and description of the trees used, and the experimental designs utilized are shown in Table 1.

All data were statistically analyzed by analysis of variance and mean separation tested by Duncan-Waller LSD (SAS Institute, Cary, N.C.).

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Table 1. Experiments conducted with PHD-Ca (1994–97).

Expt. no.	Year	Strain and cultivar	Rootstock	Tree age (years)	Method of application	Date of petal fall	Expt. design	No. replications (trees)
1	1994	Mercier St. Delicious	M.7	10	Handgun	22 Apr.	RCB ²	4
2	1995	Top Red Delicious	MM.111	13	Airblast	19 Apr.	RCB	4
3	1996	Granny Smith	M.7	11	Airblast	1 May	RCB	6
4	1997	Granny Smith	M.7	12	Airblast	15 Apr.	RCB	6
5 ³	1997	Granny Smith	M.7	13	Airblast	5 Apr.	RCB/ split plot	4
6	1997	Fuji	MM.106	15	Airblast	21 Apr.	RCB	6

²RCB = randomized complete block.

³Conducted in Laurens County, S.C. All others conducted in Henderson County, N.C.

Expt. 1. Concentrations of 0, 125, 250, and 375 mg·L⁻¹ PHD-Ca were applied 7 days after petal fall (DAPF). The 250 mg·L⁻¹ rate was also applied 0, 14, and 21 DAPF.

Expt. 2. After dormant pruning the previous winter, trees were measured and water volume for PHD-Ca spray applications was based upon TRV. Single PHD-Ca applications of 0, 125, 250, or 500 mg·L⁻¹ were applied at 21 DAPF. In addition, the 125-mg·L⁻¹ treatment was applied at both 21 and 51 DAPF. The TRV was monitored to determine the effectiveness of PHD-Ca in controlling shoot elongation and in overall tree size throughout the remainder of the growing season.

Expt. 3. Eight PHD-Ca treatments were applied between petal fall (PF) and 30 DAPF, either as single or multiple applications totaling either 250 or 500 mg·L⁻¹ (Table 6).

Expt. 4. The orchard used in 1996 was again used in 1997. Lower rates (0, 31, 62, and 94 mg·L⁻¹) of PHD-Ca were applied beginning at PF. Each concentration was applied one, two, three, or four times at 10-d intervals. An additional 125 mg·L⁻¹ was applied to treatments that showed renewed terminal budbreak and shoot extension at 60 DAPF (see Table 7). Also, treatments 4, 5, and 6 from Expt. 3 (Table 6) were retreated with the same treatments and their response was compared with trees treated for the first time in 1997.

Expt. 5. Response to PHD-Ca of an orchard at a low-elevation orchard (275 m) in Laurens County, S.C., was compared with that of a similar orchard (Expt. 4) in North Carolina at a higher elevation (700 m). Average temperatures were higher and tree vigor greater at the South Carolina site. In South Carolina, concentrations of 0, 40, 60, 80, and 100 mg·L⁻¹ were applied as four sequential sprays, beginning at PF; additionally, a 40-mg·L⁻¹ treatment applied at PF, 10 and 20 DAPF was followed at 30 DAPF with a 120-mg·L⁻¹ application. The randomized complete-block design with two trees per plot was split, and one tree per plot received an additional 125 mg·L⁻¹ at 60 DAPF.

Expt. 6. These trees were nonbearing due to a frost/freeze crop loss in 1997. The response to PHD-Ca at 200 mg·L⁻¹ was compared with that to a tank mix of daminozide at 1500 mg·L⁻¹ plus ethephon at 600 mg·L⁻¹.

RESULTS

Expt. 1. Handgun treatments in 1994 significantly reduced shoot growth (SG), but response did not differ with concentration used (Table 2). These results are similar to those reported by Green (1996). The time of application did not affect subsequent S.G. response (Table 2). Fruit set was increased by treatment at 0, 7, or 14 DAPF (Table 3). The inhibition of growth greatly reduced the amount of pruning required, measured either as number of cuts or weight of prunings (Table 3). The most graphic illustration of the influence of PHD-Ca on

Table 2. The effect of PHD-Ca treatments (time of application and concentration) on shoot length (cm) of 'Delicious' apple trees (Expt. 1, 1994).

Treatment concn (mg·L ⁻¹)	Time of application (DAFP) ²			
	0	7	14	20
0	40 a ³	---	---	---
125	---	21 b	---	---
250	13 b	23 b	21 b	19 b
375	---	18 b	---	---

²DAFP = days after petal fall.³Mean separation among all treatments by Duncan-Waller LSD, $P \leq 0.05$.

tree growth is shown in the shift in distribution of shoot length (Table 3). The treatments dramatically increased the percentage of shorter shoots (0–10 and 10–25 cm). The unusually high percentage in the shortest group for 250 mg·L⁻¹ at PF is probably an artifact of greater tissue sensitivity in the early treatment, which resulted in loss of apical dominance and growth of laterals (data not shown). This situation was not observed with other treatments or in any subsequent airblast tests.

Expt. 2. Treatments had similar effects in 1995 (SG data not shown). To illustrate the overall influence on the total tree, and the related impact on later season pesticide water application rates, data are presented as differences in TRV calculated water rates required for dilute pesticide applications (Table 4). Application of a total of 250

mg·L⁻¹ (treatments 3, 4, and 5) reduced water requirements 20% to 25% and reduced TRV more than did the 500- and 125-mg·L⁻¹ treatments. The best response was obtained with two applications of 125 mg·L⁻¹ (treatment 3).

Expt. 3. In 1996, a single application of 250 mg·L⁻¹ applied at either 7 or 21 DAFP was just as effective as 500 mg·L⁻¹ applied 21 DAFP (Table 5). However, the treatment at 7 DAFP was more effective because it was applied when less growth had occurred. When PHD-Ca was applied at 62 and 188 mg·L⁻¹ at 14 and 21 DAFP, respectively, a third application of 250 mg·L⁻¹ at 30 DAFP, which doubled the total amount of PHD-Ca applied, had no additional effect on shoot growth (Table 5). Treatments 4, 5, and 6, all of which received a total of 250 mg·L⁻¹ of PHD-Ca, differed only by the amount of extension that occurred before treatment.

Expt. 4. In 1997, regardless of the concentration used, numbers of applications or total concentration applied, all PHD-Ca treatments significantly reduced shoot length (Table 6). Trees receiving a single application of 31, single or double applications of 62 mg·L⁻¹, or a single application of 94 mg·L⁻¹ all showed regrowth by 60 DAFP and were retreated at time with 125 mg·L⁻¹. Three or four sequential applications of 31, 62, or 94 mg·L⁻¹, none of which permitted regrowth at 60 DAFP, were all equally effective (treatments 2 and 3, 6 and 7, 10 and 11).

When trees that received effective treatments in 1996 (Table 5,

Table 3. The effect of time of application of PHD-Ca (250 mg·L⁻¹) on fruit set, on pruning, and on percentage of shoots by length of 'Delicious' apple trees (Expt. 1, 1994).

Time of application (DAFP) ²	Fruit set (no./cm limb circ.)	No. pruning cuts/tree	Pruning wt (g)	Percentage of shoots by length ² (cm)			
				>10	10–25	25–40	40+
Control	4.1 a ³	111 a	1538 a	2	23	35	40
0	6.7 c	34 b	454 b	65	20	10	5
7	6.7 c	45 b	631 b	20	47	23	10
14	5.5 bc	51 b	581 b	20	55	10	15
21	4.8 ab	35 b	269 b	30	40	20	10

²No statistical analysis; observational data only.³DAFP = days after petal fall.³Mean separation with columns by Duncan-Waller LSD, $P \leq 0.05$.

Table 4. The effects of PHD-Ca application on tree growth, expressed as tree row volume (TRV) calculated – dilute pesticide (PD) water application rate, on 'Delicious' apple trees (Expt. 2, 1995).

Treatment no.	Concn (mg·L ⁻¹)	Water application rate as % of initial TRV-PD	No. applications	Timing of application (DAFP) ²	End of sason TRV (L·ha ⁻¹)	Reduction in TRV relative to control (%)
1	0	---	---	---	4357 a ³	---
2	125	100	1	21	3787 bc	13
3	125	100	2	21+51	3254 d	25
4	250	100	1	21	3506 d	20
5	250	50	1	21	3403 cd	22
6	500	100	1	21	4039 ab	7
7	500	25	1	21	4236 a	3

²DAFP = days after petal fall.³Mean separation among all treatments by Duncan-Waller LSD, $P \leq 0.05$.

Table 5. The effects of timing, concentration and sequence of applications of PHD-Ca on shoot length of 'Granny Smith' apple trees (Expt. 3, 1996).

Treatment	Concn (mg·L ⁻¹) applied at: (DAFP) ²					Total	Avg shoot length (cm)
	0	7	14	21	30		
1	0	---	---	---	---	107 DAFP	48 a ³
2	---	250	---	---	---	250	20 cd
3	---	---	---	250	---	250	30 bc
4	---	---	62	188	---	250	25 b–d
5	620	---	62	126	---	250	18 d
6	---	62	---	188	---	250	22 b–d
7	---	---	62	188	250	500	26 b–d
8	---	---	---	500	---	500	31 b

²DAFP = days after petal fall.³Mean separation among all treatments by Duncan-Waller LSD, $P \leq 0.05$.

Table 6. The effects of concentration and number of sequential applications of PHD-Ca on shoot length of 'Granny Smith' apple trees (Expt. 4, 1997).

Treatment no.	Concn applied at: (DAFP) ²					Total	Avg shoot length (cm)
	0	10	20	30	60		
1	0	---	---	---	---	0	75 a ³
2	31	31	31	---	---	93	41 b
3	31	31	31	31	---	124	31 b–d
4	31	---	---	---	125	156	29 b–d
5	62	62	---	---	125	187	24 cd
6	62	62	62	---	---	186	38 bc
7	62	62	62	62	---	248	29 b–d
8	62	---	---	---	125	187	21 d
9	62	62	---	---	125	249	23 d
10	94	94	---	---	---	188	34 bc
11	94	94	94	---	---	282	30 b–d
12	94	94	94	94	---	376	39 b
13	94	---	---	---	125	219	32 b–d

²DAFP = days after petal fall.³Mean separation among all treatments by Duncan-Waller LSD, $P \leq 0.05$.

Table 7. The effects of concentration and number of sequential applications of PHD-Ca on shoot length of 'Granny Smith' apple trees in South Carolina (Expt.5, 1997).

Treatment no.	Concn applied at: (DAPF) ²					Total	Avg shoot length (cm)
	0	10	20	30	60		
1	0	---	---	---	---	0	119 ab ³
2	0	---	---	---	125	125	120 a
3	40	40	40	120	---	240	108 a-c
4	40	40	40	120	125	365	96 b-d
5	40	40	40	40	---	160	90 c-e
6	40	40	40	40	125	285	90 c-e
7	60	60	60	60	---	240	70 ef
8	60	60	60	60	125	365	68 ef
9	80	80	80	80	---	320	60 f
10	80	80	80	80	125	445	73 d-f
11	100	100	100	100	---	400	66 f
12	100	100	100	100	125	525	74 ef

²DAPF = days after petal fall.

³Mean separation among all treatments by Duncan-Waller LSD, $P \leq 0.05$.

treatments 4, 5, and 6) were retreated in 1997, response did not differ from that of trees treated only in 1997 (data not shown).

Both four applications at 40 mg·L⁻¹ and three applications of 40 mg·L⁻¹ plus one at 120 mg·L⁻¹ were less effective than four applica-

tions of 60, 80, or 100 mg·L⁻¹ (Table 7). The three higher rates did not differ in their effects on shoot growth. Thus applying PHD-Ca in four equal applications was much more effective than applying low rates followed by a higher concentration. An additional application of 125 mg·L⁻¹ at 60 DAPF had no additional effect on growth.

Expt. 5. Shoot growth continued all summer in South Carolina, while in North Carolina growth had almost stopped by 8 July (Fig. 1). A sequence of four PHD-Ca applications at 10-d intervals beginning at PF was effective until early July at both locations. However, growth resumed in South Carolina, paralleling that of the control. The PHD-Ca treatment in North Carolina retarded growth until the control stopped growing in early July, but was unable to retard growth as effectively in South Carolina where control trees grew all summer.

Expt. 6. Application of 200 mg·L⁻¹ of PHD-Ca 21 DAPF to vigorous, nonbearing 'Fuji' trees retarded shoot growth; the effect was similar to that of a combined Alar + ethephon spray (data not shown).

DISCUSSION

Under the climatic conditions of apple-producing areas of the southeastern United States, PHD-Ca has potential for effective, season-long control of vegetative growth in apple trees. However, timing seems to be very important. Multiple, low-rate applications are more effective than a single, high-rate treatment. A concentration of 50 to 60

Fig. 1. Effects of PHD-Ca on shoot growth of 'Granny Smith' apple trees at a high (N.C.) vs. low (S.C.) elevation (Expt. 4 vs. 5, 1997).

Fig. 2. A comparison of the seasonal shoot growth curve for 'Red Delicious' apple trees at Sodus, N.Y., vs. Hendersonville, N.C. (average of 2 years per location).

mg·L⁻¹ appears to be the lower limit for multiple applications. Initial findings suggest that if PHD-Ca application rates are kept at or below 125 mg·L⁻¹ during the sensitive fruit set period (PF to 14 DAPF), fruit quality is not altered (data not shown). Response to a single PHD-CA application appears to last 3–4 weeks, suggesting that multiple applications at 2–3-week intervals are appropriate.

A comparison of vegetative growth of 'Delicious' at Sodus, N.Y. (W.H. Palmer, personal communication), and Hendersonville, N.C., suggests that growth varies with latitude and related climatic conditions (Fig. 2). By 21 DAPF shoots in New York had achieved 70% of their final length, those in North Carolina only 38%. New York trees took only 32 d to achieve 85% of total seasonal growth, but North Carolina trees required 65 d. Thus timing and concentration, as well as need for multiple applications, will probably vary in different apple production areas.

If consistent tree size control can be obtained chemically, and this appears possible based on results presented, then reduced pesticide usage should result because of the smaller tree canopies. Additionally, reduced size and canopy density could improve light penetration into trees, and therefore improve fruit quality factors such as size and/or color. Location and climate, as well as cultivar response, will affect the timing and concentrations needed.

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