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 acyclclocexanediones, are now available (Rademacher et al., 1992). Their mode of action is the inhibition of either 2β-hydroxylase (Griggs et al., 1991) or 3β-hydroxylase (Nakayama et al., 1992), which blocks gibberellin synthesis. One of these chemicals, prohexadione-Ca (BAS-125, or Apo-gee®) 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.

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.).

Received for publication 14 July 1998. Accepted for publication 20 Aug. 1998. Use of trade name does not constitute endorsement by the North Carolina Agricultural Research Service of the products named and does not imply criticism of similar ones not mentioned. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this advertisement criticism of similar ones not mentioned. 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.

**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 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. Delicieux | M.7       | 10               | Handgun              | 22 Apr.           | RCB          | 4                       |
| 2         | 1995 | Top Red Delicieux    | MM.111    | 13               | Airblast             | 19 Apr.           | RCB          | 4                       |
| 3         | 1996 | Granny Smith Delicieux | M.7       | 11               | Airblast             | 1 May             | RCB          | 6                       |
| 4         | 1997 | Granny Smith Delicieux | M.7       | 12               | Airblast             | 15 Apr.           | RCB          | 6                       |
| 5*        | 1997 | Granny Smith Delicieux | M.7       | 13               | Airblast             | 5 Apr.            | RCB          | 4                       |
| 6         | 1997 | Fuji Delicieux       | MM.106    | 15               | Airblast             | 21 Apr.           | RCB          | 6                       |

*RCB = randomized complete block.*

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

---
Table 5. The effects of timing, concentration and sequence of applications of PHD-Ca on shoot length (cm) of 'Delicious' apple trees (Expt. 1, 1994).

| Treatment | Time of application (DAPF) | Conc. (mg·L⁻¹) | 0 | 7 | 14 | 20 |
|-----------|----------------|---------------|---|---|---|---|
| Control   | 31 31 31 31 31 | 0 0 0 0 0 0   | 0 | 0 | 0 | 1 |
| 2         | 31 31 31 31 31 | 125 125 125 125 125 | 0 | 0 | 0 | 1 |
| 3         | 31 31 31 31 31 | 250 250 250 250 250 | 0 | 0 | 0 | 1 |
| 4         | 31 31 31 31 31 | 500 500 500 500 500 | 0 | 0 | 0 | 1 |

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 | Conc. applied at: (DAPF) | No. of application | Water application rate as % of initial TRV-PD | TRV (L·ha⁻¹) | Reduction in TRV relative to control (%) |
|-----------|----------------|-------------------|---------------------------------------------|-------------|----------------------------------------|
| Control   | 0 0 0 0 0 0   | 0 0 0 0 0 0     | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 2         | 31 31 31 31 31 | 125 125 125 125 125 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 3         | 31 31 31 31 31 | 250 250 250 250 250 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 4         | 31 31 31 31 31 | 500 500 500 500 500 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |

Table 3. The effect of PHD-Ca treatments (time of application and concentration) on fruit set (no./cm limb circ.) of 'Delicious' apple trees (Expt. 1, 1994).

| Treatment | Conc. (mg·L⁻¹) | 0 | 7 | 14 | 20 |
|-----------|---------------|---|---|---|---|
| Control   | 0 0 0 0 0 0   | 0 | 0 | 0 | 1 |
| 2         | 31 31 31 31 31 | 125 125 125 125 125 | 0 | 0 | 0 | 1 |
| 3         | 31 31 31 31 31 | 250 250 250 250 250 | 0 | 0 | 0 | 1 |
| 4         | 31 31 31 31 31 | 500 500 500 500 500 | 0 | 0 | 0 | 1 |

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 | Water application rate as % of initial TRV-PD | No. of applications | Timing of application (DAPF) | End of season TRV (L·ha⁻¹) | Reduction in TRV relative to control (%) |
|-----------|---------------------------------------------|-------------------|----------------|-------------------------|----------------------------------------|
| Control   | 0 0 0 0 0 0                                 | 0 0 0 0 0 0     | 0 0 0 0 0 0     | 0 0 0 0 0 0                     | 0 0 0 0 0 0                             |
| 2         | 31 31 31 31 31                                 | 125 125 125 125 125 | 0 0 0 0 0 0     | 0 0 0 0 0 0                     | 0 0 0 0 0 0                             |
| 3         | 31 31 31 31 31                                 | 250 250 250 250 250 | 0 0 0 0 0 0     | 0 0 0 0 0 0                     | 0 0 0 0 0 0                             |
| 4         | 31 31 31 31 31                                 | 500 500 500 500 500 | 0 0 0 0 0 0     | 0 0 0 0 0 0                     | 0 0 0 0 0 0                             |

Table 5. The effects 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).

| Treatment | Conc. (mg·L⁻¹) | 0 | 7 | 14 | 20 |
|-----------|---------------|---|---|---|---|
| Control   | 0 0 0 0 0 0   | 0 | 0 | 0 | 1 |
| 2         | 31 31 31 31 31 | 125 125 125 125 125 | 0 | 0 | 0 | 1 |
| 3         | 31 31 31 31 31 | 250 250 250 250 250 | 0 | 0 | 0 | 1 |
| 4         | 31 31 31 31 31 | 500 500 500 500 500 | 0 | 0 | 0 | 1 |

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 | Conc applied at: (DAPF) | No. of application | Water application rate as % of initial TRV-PD | TRV (L·ha⁻¹) | Reduction in TRV relative to control (%) |
|-----------|----------------|-------------------|---------------------------------------------|-------------|----------------------------------------|
| Control   | 0 0 0 0 0 0   | 0 0 0 0 0 0     | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 2         | 31 31 31 31 31 | 125 125 125 125 125 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 3         | 31 31 31 31 31 | 250 250 250 250 250 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
| 4         | 31 31 31 31 31 | 500 500 500 500 500 | 0 0 0 0 0 0                                 | 0 0 0 0 0 0 | 0 0 0 0 0 0                             |
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. | Conc applied at: (DAPF) | Avg shoot length (cm) |
|---------------|-------------------------|-----------------------|
|               | 0 | 10 | 20 | 30 | 60 | Total |
| 1             | 0 | --- | --- | --- | --- | 0 | 119 ab y |
| 2             | 0 | --- | --- | 125 | --- | 125 | 120 a |
| 3             | 40 | 40 | 120 | --- | --- | 240 | 108 a-c |
| 4             | 40 | 40 | 125 | --- | --- | 365 | 96 b-d |
| 5             | 40 | 40 | 40 | --- | --- | 160 | 90 c-e |
| 6             | 40 | 40 | 40 | 125 | --- | 285 | 90 c-e |
| 7             | 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 |

DAPF = days after petal fall.

Mean separation among all treatments by Duncan–Waller LSD, \( P \leq 0.05 \).

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 applications 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...
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.

Literature Cited

Griggs, D.L., P. Hedden, K.E. Temple-Smith, and W. Rademacher. 1991. Inhibition of gibberellin 2β-hydroxylases by acyclohexanecalcium derivatives. Phytochemistry 30:2513–2517.

Greene, D.W. 1996. BAS-125 10W Controls growth and influences fruit quality of ‘McIntosh’ apples, p. 283–285. In: Proc. Plant Growth Regul. Soc. Amer.

Nakayama, I., T. Miyazawa, M. Kobayashi, Y. Kamiya, H. Abe, and A. Sakurai. 1990. Effects of a new plant growth regulator, prohexadione calcium (BX-112), on shoot elongation caused by exogenously applied gibberellins in rice (Oryza sativa L.) seedlings. Plant Cell Physiol. 31:195–200.

Nakayama, I., T. Miyazawa, M. Kobayashi, Y. Kamiya, H. Abe, and A. Sakurai. 1992. Effects of a plant growth regulator, prohexadione-calcium (BX-112), on the endogenous levels of gibberellins in rice. Plant Cell Physiol. 33:59–62.

Rademacher, W., K.E. Temple-Smith, D.L. Griggs, and P. Hedden. 1992. The mode of action of acyclohexanones—A new type of growth retardant, p. 571–577. In: Progress in plant growth regulation. Kluwer Academic Publishers, The Netherlands.

Sutton, T.B. and C.R. Unrath. 1988. A comparison of handgun and tree-row-volume pesticide applications. Plant Dis. 72:509–512.