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Effects of Directed Applications of Prohexadione-Calcium to Tops of Mature Pear Trees on Shoot Growth, Light Penetration, Pruning and Fruit Quality

DON C. ELFVING[1], LEONARDO LOMBARDINI[2], JAMES R. MCFERSON[3], STEPHEN R. DRAKE[4], DANA F. FAUBION[5], THOMAS D. AUVIL[6], GARY VAN EE[7] AND DWAYNE B. VISSER[8]

Abstract

Low-volume application of prohexadione-calcium (P-Ca, Apogee® BASF Corp.) to tops of mature pear trees reduced the vigor of shoot growth in relation to time of application, number of applications and amount of P-Ca applied. However, a second, late-summer flush of elongation of treated shoots occurred in most P-Ca treatments. Untreated trees did not produce a second growth flush. If shoot elongation in the tops of treated 'Bartlett' pear trees was reduced more than 60%, the time required for dormant pruning entire trees was also reduced. Time to summer prune 'd'Anjou' trees was reduced by treatment with P-Ca. In two of the three trials reported here, the weight of prunings removed from whole trees was reduced in proportion to the amount of P-Ca applied to the top halves of the canopies only. P-Ca treatment improved light penetration into the lower portion of the canopy in mature 'd'Anjou' pear trees whose canopies nearly touched in the row. 'Bartlett' fruit size was decreased when high concentrations of P-Ca were applied during the cell-division phase of fruit development. P-Ca produced few changes in 'Bartlett' pear fruit quality characteristics at harvest, all of which disappeared after two months of air storage. Chemical names used: calcium 3-oxido-4-propionyl-5-oxo-3-cyclohexene carboxylate (prohexadione-Ca); polyoxyethylenepolypropoxypropanol, dihydroxypropane, 2-butoxyethanol (Regulaid®).

Introduction

The Washington State pear industry is still based primarily on mature trees on seedling rootstocks. These trees are normally trained to the open-center system and develop a globular-shaped canopy. Such trees typically produce a substantial amount of shoot growth in the tops of the trees each year. This growth must be thinned out or removed annually to maintain tree height and provide satisfactory light penetration into the lower canopy. Dormant and/or summer pruning are used to adjust canopy structure and improve light distribution in mature pear trees in Washington.

Flower bud formation in pear is impaired by low light conditions in the canopy (33). Greater flower bud density, fruit set and fruit size in 'd'Anjou' pear were associated with higher sunlight interception in a study of tree row orientation

[1]Horticulturist and Professor. Tree Fruit Research & Extension Center, Washington State University Wenatchee, WA 98801 USA
[2]Postdoctoral Research Associate. Present address: Dept. of Horticultural Sciences, Texas A & M University, College Station, TX 77843.
[3]Horticulturist and Manager, Washington Tree Fruit Research Commission, 1719 Springwater St., Wenatchee, WA 98801.
[4]Research Horticulturist, USDA/ARS Tree Fruit Research Laboratory, 1104 N. Western Ave., Wenatchee, WA 98801.
[5]Extension Horticulturist, Yakima County Cooperative Extension, 128 N. 2nd St. Yakima WA 98901.
[6]Research Horticulturist, Washington Tree Fruit Research Commission, 1719 Springwater ST., Wenatchee, WA 98801.
[7]Professor, Dept. of Agricultural Engineering, Michigan State University, East Lansing, MI 48824.
[8]Agricultural Technician II. Tree Fruit Research & Extension Center, Washington State University Wenatchee, WA 98801 USA

and canopy location (18). In other studies, pear fruit size was positively correlated with amount of light received by the spurs (17). Light plays a fundamental role in influencing fruit quality characteristics, such as color, soluble solids concentration and fruit weight (24).

Vigorous shoot growth in pear trees can reduce light penetration into the canopy (8,22). Different strategies have been evaluated for reduction of the impact of vigorous shoot growth in pear trees while minimizing added costs. Mechanical hedging of pear trees can reduce pruning time (21,28) but the concomitant stimulation of shoot growth can also reduce light penetration into the canopy without follow-up hand pruning (3). The majority of the vigorous shoot growth in mature pear trees in Washington State takes place in the upper portion of the canopy. Reduction in shoot growth vigor or removal of vigorous growth in the upper canopy can improve light penetration into the lower canopy (8) and reduce pruning requirements (22).

Many trials have shown that chemical inhibitors of gibberellic acid biosynthesis such as daminozide, paclobutrazol and chlormequat reduce vegetative vigor in pear trees (2,4,7,11,16,23,27). However, none of these products is available for commercial use on pear trees in Washington State at the present time.

Nicotra et al. (23) reported no difference in growth response to chlormequat applied to either the upper third vs. the entire canopy in 'Comice' trees until the fourth year of repeat treatments. No other reports of applications of growth inhibitors to the tops of pears trees are known. Applying daminozide to tops reduced the vigor of shoot growth in mechanically hedged apple trees (14), but no similar work has been reported in pear, either with dilute or low-volume application methods.

The principal mode of action of P-Ca in reducing shoot extension growth in pear trees results from its inhibitory effects on the biosynthesis of active gibberellic acid (GA) isomers in plant tissues (6, 10, 12, 25, 32). Pear growers do not have access to the range of vigor-controlling rootstocks typically used in commercial apple production; mature pear orchards in Washington consist almost exclusively of large trees on seedling rootstocks. The studies reported here were conducted during three growing seasons (1999-2001) to evaluate the potential of low-volume P-Ca applications directed to the upper portion of the canopies of mature pear trees for: a) reduction of shoot growth in the tops, b) improvement of light penetration into the lower canopy, c) effects, if any, on amount of dormant or summer pruning required following treatment, and d) effects, if any, on fruit size, quality and pack-out.

Materials and Methods

Trial 1, 'Bartlett' pear, Wapato, Wash., 1999.

Five blocks, each containing five 3-tree plots, were established in a 43-year-old 'Bartlett'/seedling orchard spaced at 3.3 x 6 m (10 x 20 ft) in east-west-oriented rows in April, 1999. Trees received the normal annual pruning the previous winter. Treatments consisted of an untreated control and four different P-Ca application-timing combinations using a low-volume, tower airblast sprayer (Proptec™, Ledebuhr Industries, Inc., Bath, Mich.). This machine delivered each spray only to the upper half of treated trees in a water volume of 280 liters/ha. The surfactant Regulaid® (Kalo, Inc., Overland Park, Kan.) was added to each spray solution at 1 ml per liter water (0.1% v/v). On the date of each application, an estimate of tree row volume for the upper half of the tree canopies was made (29, 30); that volume was used to calculate the amount of P-Ca to be applied per ha that would be equivalent to a dilute application of a 500 mg a.i. P-Ca per liter solution. Lower fans supplied only air to minimize unintentional application of P-Ca to the lower portion of the canopy. Treatments were assigned at random to the 3-tree plots in each randomized complete-block (5 replicates per treatment). In each block, each plot was separated from adjacent plots in the row by single guard trees. Each block was placed in a separate row 18 m away from the nearest adjacent block.

The particulars for each application are listed below:

1. 5 May: top half tree row volume = 935 l/ha; 420 g a.i. P-Ca applied per ha;
2. 24 May: top half tree row volume = 1120 l/ha; 560 g a.i. P-Ca applied per ha;
3. 18 June, 15 July: top half tree row volume = 1400 l/ha; 700 g a.i. P-Ca applied per ha.

Each P-Ca treatment was applied to five separate 3-tree plots as follows:

1. Control (unsprayed);
2. P-Ca applied three times, on 5 May, 24 May, and 18 June (total of 1680 g a.i. P-Ca applied per ha);
3. P-Ca applied twice, on 24 May and 18 June (total of 1260 g a.i. P-Ca applied per ha);
4. P-Ca applied once on 18 June (total of 700 g a.i. P-Ca applied per ha);
5. P-Ca applied twice, on 18 June and 15 July (total of 1400 g a.i. P-Ca applied per ha).

Four newly-developing terminal shoots were tagged in the top of each tree in each 3-tree plot at the time the particular treatment sequence was initiated and their initial lengths recorded. Shoots on control trees were tagged and measured at the same time as the first application of P-Ca was made. The length of each tagged shoot was measured once or twice per week through the end of August and again in late September. The total time required for one experienced orchard worker to dormant-prune each 3-tree plot was measured on 19 Jan. 2000. All shoot material removed during pruning was collected from each 3-tree plot and weighed following pruning.

An approximately 70-fruit sample was collected from the top half and another from the bottom half of each tree in each 3-tree plot at commercial harvest on 18 Aug. 1999. Commercial harvest date was based on when fruit met the processing requirement of 11% soluble solids in juice expressed from fruit flesh. Each fruit sample was counted and total weight determined. The harvested fruit from the top halves of the three trees in each plot were combined into one overall plot sample from tops; the same procedure was carried out on the harvested fruit from the bottom halves of the three trees in each plot. A subsample of 25 fruit from the top halves and another from the bottom halves of each plot was placed in a "V"-shaped trough and total fruit length and diameter determined for fruit shape assessment. A subsample of 40 pears from the top halves and another from the bottom halves of each plot was taken to the USDA/ARS Tree Fruit Research Laboratory in Wenatchee, WA for fruit quality assessment and storage.

Upon arrival, twenty pears from each fruit sample were immediately analyzed for harvest quality; another subsample of 20 pears from each fruit sample was placed in regular air storage at 1°C for removal and evaluation after two months of storage. Fruit quality factors evaluated were flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), skin color and incidence of visually dectectable disorders (scald, shrivel, black speck, pithy brown core). Firmness was determined using the TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, NY) equipped with a 7.7-mm probe. External color was determined with The Color Machine (Pacific Scientific, Silver Springs, MD) using the Hunter L*, a*, b* system and calculated hue angle values (15). SSC and TA were determined from a composite of juice expressed from longitudinal slices from each of 10 fruit. An Abbè type refractometer with a sucrose scale calibrated at 20°C was used to determine SSC. TA was measured with a Model TTT85 Radiometer titrator (Radiometer, Copenhagen, DK). Acids were titrated to pH 8.2 with 0.1N NaOH and expressed as percent malic acid equivalent. After 2 months of air storage, the remaining 20 pears from each sample were evaluated according to the above procedures. Disorders were evaluated by laboratory personnel familiar with pear disorders.

Trial 2, 'd'Anjou' pear, Cashmere, Wash., 2000.

Six blocks of three single-tree plots each were established in one row of a 51-year-old 'd'Anjou'/seedling orchard spaced at

4.6 x 9.1 m (15 x 30 ft) in north-south-oriented rows in April, 2000. Each plot was separated from adjacent plots by single guard trees. Trees received the normal annual pruning the previous winter. Canopies of adjacent trees were close to being in contact in the row. Treatments consisted of an unsprayed control and two different total P-Ca quantities per ha (200 or 300 g P-Ca per ha), each applied only to the top halves of the tree canopies in two applications three weeks apart using a low-volume, tower airblast sprayer (Propteç™, Ledebuhr Industries, Inc., Bath, Mich.) in a water volume of 280 liters/ha for each application. The surfactant Regulaid® (Kalo, Inc., Overland Park, Kan.) was added to each spray solution at 1 ml per liter water (0.1% v/v). On the date of each application, an estimate of tree row volume for the upper half of the tree canopies was made (29,30); that volume was used to calculate the amount of P-Ca to be applied per ha that would be equivalent to the application of either an 83 mg a.i. P-Ca per liter or a 125 mg a.i. P-Ca per liter dilute application. Lower fans supplied only air to minimize unintentional application of P-Ca to the lower portion of the canopy. Treatments were assigned at random to the plots in each randomized complete-block (6 replicates per treatment).

The particulars for each application are listed below:

1. 2 May: top half tree row volume = 840 l/ha;
   a) 83 mg a.i./liter: 70 g a.i. P-Ca applied per ha;
   b) 125 mg a.i./liter: 110 g a.i. P-Ca applied per ha.
2. 24 May: top half tree row volume = 1400 l/ha;
   a) 83 mg a.i./liter: 120 g a.i. P-Ca applied per ha;
   b) 125 mg a.i./liter: 180 g a.i. P-Ca applied per ha.

P-Ca treatments were applied on 2 May and again on 24 May to the single-tree plots as follows:

1. Control (unsprayed);
2. P-Ca (83 mg a.i. P-Ca/liter dilute equivalent): total of 200 g a.i. P-Ca applied per ha;
3. P-Ca (125 mg a.i. P-Ca/liter dilute equivalent): total of 300 g a.i. P-Ca applied per ha. In each treatment, approximately one-third of the total amount of P-Ca was applied in the first spray and two-thirds in the second spray.

Four typical newly-developing terminal shoots were tagged in the top of each single-tree plot on 19 May and their initial lengths recorded. The length of each tagged shoot was measured once per week until the trees were summer-pruned (21 July 2000). The time required for one experienced orchard worker to summer-prune each single-tree plot was measured on 21 July, 2000. All shoot material removed during pruning was collected from each plot and weighed immediately following pruning. Light penetration was measured at dawn but prior to sunrise at four locations representing the cardinal directions around the trunk of each single-tree plot. Measurements were collected 1 m from the trunk at 1 m and 2 m above the soil surface (approximately one-fourth and one-half of total canopy height (8) on 21 July (before summer pruning) and again on 24 July (after summer pruning) using a Li-Cor Model LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., Lincoln, Nebr.). In each plot, the instrument was standardized to the ambient light level above the canopy before measurements were made. No fruit were harvested for evaluation in this trial.

Trial 3, 'Bartlett' pear, Palisades, Wash., 2001.

Four blocks of three 12-tree plots each were established in a 38-year-old 'Bartlett'/seedling orchard spaced at 6.1 x 6.1 m (20 x 20 ft) in north-south-oriented rows in April, 2001. Trees received the normal annual pruning the previous winter. Each plot consisted of four trees in each of three adjacent rows (12 trees per plot in a rectangular configuration). Each plot was separated from adjacent plots by at least two guard trees in the same rows.

Treatments consisted of an unsprayed control and two different total P-Ca quantities per ha (300 g or 600 g P-Ca per ha), each applied to the top halves of the tree canopies in two applications three weeks apart using a low-volume, tower airblast sprayer (Proptec™, Ledebuhr Industries, Inc., Bath, Mich.) in a water volume of 280 liters/ha for each application. The applications were designed so that one-third of the total active ingredient was applied in the first spray and the remaining two-thirds in the second application. The surfactant Regulaid® (Kalo, Inc., Overland Park, Kan.) was added to each spray solution at 1 ml per liter water (0.1% v/v). Lower fans supplied only air to minimize unintentional application of P-Ca to the lower portion of the canopy. Treatments were assigned at random to the 12-tree plots in each randomized complete-block (4 replicates per treatment).

Each of the P-Ca treatments was applied on 4 May and again on 24 May to separate twelve-tree plots as follows:

1. Control (unsprayed);
2. P-Ca (total of 300 g P-Ca per ha): 4 May, 100 g a.i. P-Ca applied per ha; 24 May 200 g a.i. P-Ca applied per ha;
3. P-Ca (total of 600 g P-Ca per ha): 4 May, 200 g a.i. P-Ca applied per ha; 24 May 400 g a.i. P-Ca applied per ha.

Three newly-developing terminal shoots were tagged in the top of each of two trees in the center of each 12-tree plot on 9 May and their initial lengths recorded. The length of each tagged shoot was measured once per week until early October, 2001. The overall time required for two experienced orchard workers to dormant-prune those same two trees in each plot was measured on 13 Feb. 2002. All material removed during pruning was collected from each 2-tree sub-plot and weighed following pruning.

Light penetration was measured at weekly intervals from late April to late September following the same procedures as described for Trial 2. Data values were standardized to the ambient light level above the canopy before measurements were made in each plot.

All fruit from each 12-tree plot were commercially harvested into bins on 17 Aug. 2001. Commercial harvest was based on when a sample of fruit met the fresh-market requirement of an average fruit flesh firmness of approximately 71 N (16 lb). The bins of harvested fruit were marked by treatment for later identification for overall pack-out data for each treatment. All fruit from each treatment were stored in a commercial fruit storage in air at 0°C; the fruit from each treatment was packed separately on a commercial pear packing line (Blue Star Growers, Inc., Cashmere, Wash.) on 10 Dec. 2001.

At harvest, 60 pears were collected from each plot and weighed. Twenty pears from each sample were immediately analyzed for harvest quality parameters as described above. The remaining 40 pears from each sample were placed in regular air storage at 1°C. On 14 Oct. 2001, 20 pears from each sample were removed for fruit quality analysis as described. The remaining 20 pears from each sample were placed at room temperature (≈20°C) and evaluated after four days (estimate of shelf life).

Data were evaluated by analysis of variance or regression using the General Linear Models (GLM) procedure of the Statistical Analysis System program package (SAS Inst., Cary, NC). Where significant F-tests were observed ($P \leq .05$), treatment means were separated using the Waller-Duncan Bayesian k-ratio test.

Results

Trial 1, 1999.

Untreated trees exhibited pattern 1 of pear shoot growth (10), with continuous and nearly steady terminal-shoot extension growth from initiation to cessation some 4 months later (Figure 1). P-Ca reduced shoot elongation rate whenever applications were initiated. Delaying the start of P-Ca treatment permitted shoot growth to proceed at the normal pace for a longer time, resulting in less reduction in total shoot elongation. Shoot growth rate

was initially reduced to the same extent by P-Ca treatment regardless of when treatments were begun. All P-Ca treatments resulted in terminal shoot growth in the tops of the trees that was shorter at the end of the growing season than in untreated trees, but treatments in which applications were made earlier in the growing season were more effective for reducing shoot growth.

A second flush of shoot growth (Growth pattern 4, from ref. 10) developed at the end of July in all of the P-Ca treatments (Table 1). The control trees did not produce a comparable flush. This second flush was most discernible in the treatments in which P-Ca was applied either twice or only once. The date of the final application of P-Ca in any of the treatment sequences appeared to have no effect on the initiation of the second flush. The time during the season when initiation of the second flush took place and the rate of shoot elongation during this second flush were identical for the P-Ca treatments applied only on 18 June or applied on 18 June and again on 15 July. The 15 July P-Ca application was made only a few weeks before the second growth flush began. Although the treatment in which P-Ca was applied on both 18 June and 15 July received twice as much P-Ca in total as the treatment applied only once on 18 June,

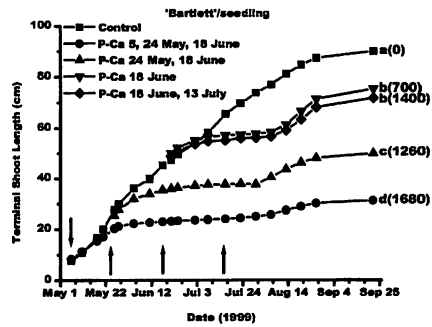


Figure 1. Terminal shoot extension growth in the tops of 43-year-old 'Bartlett'/seedling trees in which the top halves of the canopies were treated with P-Ca on various dates (Trial 1). Final terminal shoot length means followed by different letters are significantly different by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$). Numbers in parentheses represent the total amount of P-Ca (g.a.i.) applied per ha for each treatment program.

Table 1. Late summer terminal shoot growth in tops of 43-year-old 'Bartlett'/seedling pear trees treated with P-Ca in the upper half of the canopy (Trial 1, 1999)

Treatment[Z,Y]	Mean shoot length 23 July (cm)	Mean daily shoot extension (cm/day) 23-30 July	30 Jul - 6 Aug	6-13 Aug	13 - 20 Aug	20 - 27 Aug	Mean shoot length 27 Aug (cm)
Control	70a	0.6a	0.5a	0.6a	0.5abc	0.4ab	87a
P-Ca 5, 24 May, 18 June, 1680 g/ha	24d	0.1b	0.1b	0.2a	0.2c	0.2b	30d
P-Ca 24 May, 18 June, 1260 g/ha	38c	0.1b	0.3ab	0.5a	0.4bc	0.3b	48c
P-Ca 18 June, 700 g/ha	57b	0.0b	0.1b	0.4a	0.8a	0.7a	71b
P-Ca 18 June, 15 July 1400 g/ha	56b	0.0b	0.1b	0.4a	0.6ab	0.7a	68b

[Z]Dates of application and total amount of P-Ca applied per ha.
[Y]Means followed by different letters are significantly different by the Waller-Duncan Bayesian k-ration test ($p \leq .05$).

there was no difference between these two treatments on either the time of initiation of the second flush or the rate of shoot growth during the flush.

Pruning time was reduced only by the treatment including 3 applications of P-Ca; this treatment produced maximum control of shoot growth (final mean shoot length 35% of control, Table 2). This treatment also had the lowest weight of prunings removed from entire trees, but this value was not different from the control.

Fruit from trees treated with P-Ca on either or both 5 May and 24 May were smaller than untreated fruit or fruit from trees treated with P-Ca beginning 18 June (Table 3). These treatments were initiated while the fruit were still in the cell-division phase of growth (34). No data were collected on fruit set or total tree yield. Fruit shape was unaffected by P-Ca treatment (data not shown).

Table 2. Dormant pruning the winter following applications of P-Ca to upper halves of the canopies of 43-year-old 'Bartlett'/seedling pear trees (Trial 1, 1999).

Treatment[Z,Y]	Pruning time		Weight of prunings removed
	Min/tree[X]	hr/ha[W]	(kg f.w./tree)
Control	20.8a	187a	10.9ab
P-Ca 5, 24 May, 18 June 1680 g/ha	10.9b	98 b	7.6b
P-Ca 24 May 18 June 1260 g/ha	17.4ab	156ab	11.0ab
P-Ca 18 June 700 g/ha	15.1ab	135ab	11.9a
P-Ca 18 June, 15 July, 1400 g/ha	14.8ab	133ab	12.5a

[Z]Dates of application and total amount of P-CA applied per ha.
[Y]Means followed by different letters are significantly different by the Waller-Duncan Bayesian k-ratio test (p≤.05)
[X]Mean time for one pruner to prune a single tree.
[W]Estimated time for one pruner to dormant-prune one ha.

At harvest, all sampled fruit had achieved the 11% SSC requirement for processing (Table 3). Fruit firmness at harvest was greater for all P-Ca treatments compared to control, regardless of the presence or absence of treatment effects on fruit size. SSC and TA did not appear affected by P-Ca, but the treatments starting in June resulted in a more yellow skin color even though flesh firmness values were greater. No physiological disorders were noted at harvest (data not shown). Following two months of air storage, pears from all treatments showed no differences in flesh firmness, SSC, TA, external skin color or physiological disorders (data not shown). Fruit samples from the upper portion of the canopy were firmer at harvest and displayed a more yellow skin color, but did not differ in any other way. After the pears were removed from storage, firmness and color differences related to canopy location had disappeared (data not shown).

Trial 2, 2000.

Untreated trees exhibited the "normal" shoot growth pattern (10) with a single, strong flush followed by a steadily decreasing shoot growth extension rate until cessation (Fig. 2). Both P-Ca application programs reduced shoot extension growth to the same extent. No second shoot growth flush was observed prior to summer pruning.

Treatment with P-Ca substantially reduced the time required for summer pruning entire trees (Table 4). The amount of leafy shoot material removed during summer pruning was substantial in the control trees. P-Ca application to the top halves of the canopies reduced the amount of leafy shoot growth removed during summer pruning, contributing to the reduction in time required to complete summer pruning.

Both P-Ca and summer pruning altered light distribution in the canopy (Fig. 3). Treatment with P-Ca improved light penetration at 2 m above the soil surface (approximately halfway between top and soil surface) prior to summer pruning, but had no effect at 1 m. After summer pruning was done, control percent visible sky lev-

Table 3. Fruit weight and quality characteristics at harvest of pears from 43-year-old 'Bartlett'/seedling trees treated in the upper halves of the canopy with P-Ca (Trial 1, 1999).

Treatment[Z,Y]	Mean fruit weight (gm)	Flesh firmness (N)	Total soluble solids (%)	Titratable acidity (%)	Solids/acid ratio	External hue (°)
Control	170a	32b	11.4ab	0.318a	36a	98.7b
P-Ca 5, 24 May, 18 June 1680 g/ha	160b	45a	11.3ab	0.323a	35a	101.1ab
P-Ca 24 May 18 June 1260 g/ha	160b	47a	11.1b	0.322a	35a	101.7ab
P-Ca 18 June, 700 g/ha	170a	44a	11.5a	0.337a	34a	102.5a
P-Ca 18 June 15 July, 1400 g/ha	170a	42a	11.5a	0.341a	34a	102.0a
Canopy location						
Upper half	170a	47a	11.5a	0.334a	35a	102.0a
Lower half	160a	37b	11.3a	0.323a	35a	100.9b

[Z]Dates of application and total amount of P-Ca applied per ha.
[Y]Means followed by different letters are significantly different by the Waller-Duncan Bayesian k-ratio test (p≤.05).

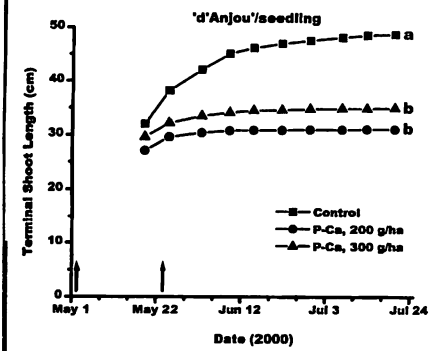


Figure 2.Terminal shoot extension growth in the tops of 51-year-old 'd'Anjou'/seedling pear trees in which the top halves of the canopies were treated with P-Ca on two dates (Trial 2). Final terminal shoot length means followed by different letter are significantly different by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).

Table 4. Summer pruning of 51-year-old 'd'Anjou'/seedling pear trees following spring application of P-Ca to the upper halves of the canopy (Trial 2, 2000).

Treatment[Z,Y]	Summer pruning time min/tree[X]	Summer pruning time hr/ha[W]	Weight of prunings removed (kg f.w./tree)
Control	7.5	29.8	6.0
P-Ca 2, 24 May 200 g/ha	3.4	13.6	2.0
P-Ca 2, 24 May 300 g/ha	5.2	20.9	3.0
Significance			
Linear	*	*	*
Quadratic	*	NS	NS

[Z]Dates of application and total amount of P-Ca applied per ha.
[Y]Significance of linear and quadratic effects by regression analysis on total amount of P-Ca applied per ha. NS = nonsignificant, *=effect significant (p≤.05).
[X]Time for one pruner to prune each single-tree plot.
[W]Estimated time for one pruner to summer-prune one ha.

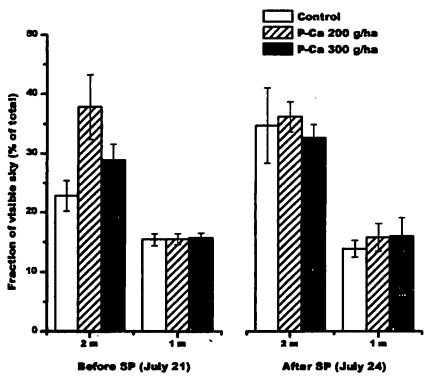


Figure 3. Percentage of visible sky prior to and following summer pruning of 51-year-old 'd'Anjou'/seedling trees in July, 2000 (Trial 2).

els were higher at the 2-m location than before summer pruning and differences due to P-Ca treatment had disappeared. The vigorous growth of leafy shoots in the untreated trees prior to summer pruning had an unfavorable effect on light distribution in the lower portion of the canopy. Improved light distribution in the lower portions of the canopy would be expected to improve production and fruit quality in the lower portion of the tree (8,17,33).

Trial 3, 2001.

Untreated trees exhibited the "normal" shoot growth pattern (10) with a single, strong flush followed by a steadily decreasing shoot growth extension rate until cessation (Figure 4). In contrast, the P-Ca-treated trees exhibited growth pattern 2, with two approximately equally vigorous flushes, separated by about 4 weeks of virtually no shoot elongation activity. Despite the second flush, P-Ca treatments reduced shoot length compared to untreated trees (final shoot lengths 78 and 80% of control). The total amount of P-Ca applied in the two sprays did not appear to differentially influence the rate of shoot extension growth during the growing season, the time of the initiation of the second growth flush, or the final length of terminal shoots in the tops of the trees. No differences were observed in light levels in the lower canopy at any time during the season (data not shown). Even though P-Ca treatment substantially reduced shoot growth during the first half of the growing season, the absence of differences in light penetration may have been due to the fact that these trees had not filled their space to the same extent as the trees in Trial 2.

In this trial the time required for dormant pruning entire trees was not affected by P-Ca treatment to tops (Table 5). However, the amount of vegetative material removed appeared to be inversely related to the amount of P-Ca applied to the tops of the trees. The reduction in shoot growth from P-Ca treatment in this trial, though significant, was substantially less relative to the control than in Trial 1. The pruning results suggest that the P-Ca treatments did not reduce the number of pruning cuts required but did reduce the total fresh weight of wood removed during dormant pruning.

At harvest, fruit firmness was not different among treatments and was very close to the fresh-market harvest criterion of approximately 71N (16 lb, data not shown). Fruit weight, SSC, TA and skin color were not different among treatments at harvest (data not shown). After two months of storage in air at 1°C, the fruit

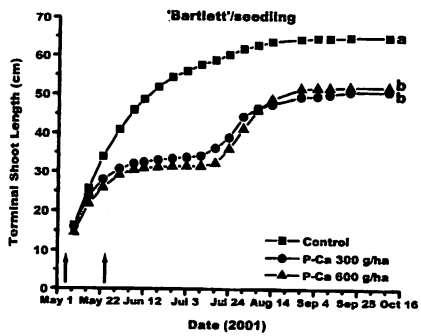


Figure 4. Terminal shoot extension growth in the tops of 38-year-old 'Bartlett'/seedling pear trees in which the top halves of the canopies were treated with P-Ca on two dates (Trial 3). Final terminal shoot length means followed by different letters are significantly different by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).

Table 5. Dormant pruning of 38-year-old 'Bartlett'/seedling pear trees following applications of P-Ca to the upper half of the canopy. Trial 3, 2001.

Treatment[Z,Y]	Pruning time min/tree[X]	Pruning time hr/ha[W]	Weight of prunings removed (kg f.w./tree)
Control	25.4	46	33.2
P-Ca-4, 24 May, 300 g/ha	24.1	44	30.3
P-Ca 4, 24 May 600 g/ha	22.8	41	25.2
Significance			
Linear	NS	NS	**
Quadratic	NS	NS	NS

[Z]Dates of application and total amount of P-Ca applied per ha.
[Y]Significance of linear and quadratic effects by regression analysis on total amount of P-Ca applied per ha. NS = nonsignificant, **= effect significant ($p \leq .01$).
[X]Mean time for one pruner to dormant prune a single tree.
[W]Estimated time for one pruner to dormant-prune one ha.

showed no treatment effects on any parameter measured (data not shown).

Fruit pack-out data in Trial 3 could not be statistically analyzed because of the combining of replicates to provide enough fruit to operate the grading line independently for each treatment. The total quantity of fruit from the four replicates of each treatment was approximately equivalent (Table 6). The number of approximately 19-kg fresh-market packed boxes was not influenced by P-Ca treatment. Higher P-Ca doses appeared to reduce the quantity of fruit diverted to processing and to increase cull-out. Although the amount of fruit removed during grading appeared to be greater with increased P-Ca, small fruit size did not contribute to that increase. The increase in cullage was due primarily to an increase in "pink-end" and "hard-end" with higher P-Ca doses. Pink end or premature ripening of 'Bartlett' pears is a problem associated with cooler growing

Table 6. Pack-out and causes of cullage of total pear crop for each P-Ca application treatment to upper halves of the canopy of 38-year-old 'Bartlett'/seedling pear trees (Trial 3, 2001).

Treatment[Z]	Bins fruit per treatment[Y]	19-kg. packed-box equivalents (No.) Fresh market	Canner	Cull	Total
Control	11	227	35	2	264
P-Ca 4, 24 May, 300 g/ha	11	238	29	6	273
P-Ca 4, 24 May, 600 g/ha	11	234	21	10	265

[Z]Dates of application and total amount of P-Ca applied per ha.
[Y]Total fruit per treatment (4 twelve-tree plots combined per treatment.)

Treatment[Z]	Cause of cullage (% of total culls) Lime rub	Pedicel puncture	Small size	Pink end and hard end	Other
Control	36	11	28	0	25
P-Ca 4, 24 May 300 g/ha	31	6	6	20	37
P-Ca 4, 24 May 600 g/ha	37	0	12	41	10

[Z]Dates of application and total amount of P-Ca applied per ha.

temperatures (20). P-Ca may predispose 'Bartlett' pears to a greater amount of this disorder. Hard end is a disorder associated with unfavorable water relations in the tree (1,5,26). Bullock and Ackley (5) suggested that applications of plant hormones may have an influence on internal water relations and possibly on hard-end incidence, but no data exist that demonstrate such an effect of P-Ca.

Discussion

The circumstances which determine whether a second flush of shoot growth will occur are not clearly understood. P-Ca has a short effective lifetime in tissues of fruit trees (12). It exerts its shoot growth-controlling influence at the last stage in GA biosynthesis by inhibiting the conversion of inactive GA isomers into active forms (12,25). If inactive GA isomers accumulate while P-Ca - mediated growth control is active, there might be a rapid production of active GA when the inhibitory P-Ca effect diminishes or disappears. A second flush of shoot growth in late summer was observed in two of the three trials reported here; such a flush might have been observed in Trial 2 had the trees not been summer pruned.

The most effective strategy for controlling a second shoot growth flush is still unclear. Application of P-Ca very near to the time of initiation of the second flush appears to be ineffective for controlling that flush. Results of the trials reported here suggest that three or more P-Ca applications during the spring/early-summer component of the growing season may be necessary to minimize the formation of a later growth flush. The relation of P-Ca dose and number of applications to the development of a second growth flush has not been carefully investigated in vigorous pear trees. Multiple P-Ca applications beginning in spring have been successful for providing season-long shoot growth control in apple under climatic conditions in the southeastern USA that produce the same tendency for an extended period of vegetative growth as observed in pear trees under Washington conditions (31).

Results of trials reported here suggest that P-Ca would be most effective for control of growth in the tops of pear trees if those trees fill much or most of their allocated space in the orchard, the vegetative growth in the tops is substantial, and the P-Ca application program produces a very significant reduction in shoot length in the treated zone (>50% reduction). P-Ca does not reduce the number of shoots in active growth (10). Therefore, a reduction in pruning time would only be expected where there was sufficient reduction in shoot elongation to permit more shoots to be left in the tree, (i.e., fewer pruning cuts). The fact that a reduction in shoot growth in the tops can reduce the time required to prune entire mature pear trees suggests that pruning the tops is relatively time-consuming. Ladders are needed to reach the tops of mature pear trees. Ladder use during pruning substantially increases the time required to prune trees (9).

Improved light penetration into the lower canopy appeared to be dependent on both the amount of shoot growth in the upper canopy and the degree to which individual trees influenced the light in nearby trees. Chemical control of vegetative growth in the tops of trees would likely improve light climate only where growth is quite vigorous and the trees had nearly or completely filled their allocated space in the orchard.

A small reduction in 'Bartlett' pear fruit size ($\approx$ 6%) from P-Ca treatment was only observed in 1999 under conditions of high concentrations of P-Ca applied during the cell-division phase of fruit development and detailed harvest-sample fruit-weight analyses. In 2001, applications of lower concentrations of P-Ca at approximately similar timings produced no noticeable effect on fruit size in the total crop. It is possible that cell division may have been inhibited and/or fruit-set increased by the high concentrations of P-Ca in 1999. A similar effect was reported for the GA biosynthesis inhibitor daminozide on apple when applied during the cell-division phase of growth (19). P-Ca has been reported to increase apple fruit set (13).

Costa et al. (6) reported no effect of P-Ca on fruit set in 'Abate Fetel' pear at concentrations much below those used in Trial 1.

Limited P-Ca effects on 'Bartlett' pear fruit quality at harvest were observed in 1999, but those differences disappeared after a short period of storage. Because fruit in 1999 were harvested for processing, they were more mature at harvest than if harvested for fresh-market use. In 2001, 'Bartlett' pears harvested based on fresh-market harvest criteria showed no effects of P-Ca on any fruit quality or disorder parameter, either at harvest, after air storage or after a short period of exposure to ambient temperatures to simulate potential shelf life. Again, the 1999 results may have reflected the high amounts of P-Ca used in that trial. These trials suggest that P-Ca has little or no beneficial effect on fruit maturity or quality in 'Bartlett' pear.

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