Interactive Effects of Pruning and Cyclanilide Application on Growth of Woody Nursery Crops[1]

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Abstract

A study was conducted to determine the effects of pruning on plant response to cyclanilide (CYC), a bioregulator that promotes lateral branching of fruit trees and selected woody nursery crops. In April 2004, non-pruned 'Elizabeth Ann' Japanese camellia (*Camellia japonica* L.) and small anisetree (*Illicium parviflorum* Michx. ex Vent.) received a single foliar application of 0, 25, 50, 100 or 200 ppm CYC, while the same species received a foliar spray of 0, 50 or 100 ppm CYC following uniform pruning. In June 2006, a single foliar application of 0, 100 or 200 ppm CYC was made to plants of ternstroemia (*Ternstroemia gymnanthera* Thunb.), 'Sky Pencil' holly (*Ilex crenata* Thunb.) and 'Jennifer' azalea (*Rhododendron* L.) that were either not pruned or uniformly pruned before CYC treatment. At 30 and 60 days after treatment (DAT), non-pruned, CYC-treated plants formed more shoots than pruned CYC-treated plants, however quality ratings at 120 DAT were generally higher in plants pruned prior to CYC treatment. In a third experiment, the effects of 200 ppm CYC on branching of ternstroemia, 'Sky Pencil' holly, 'Jennifer' azalea and 'Snow White' Indian hawthorn were ascertained when applied at three stages of lateral shoot development following pruning: immediately after pruning [developmental stage 1 (DS 1)], when new shoots were 1.3 to 2.6 cm (0.5 to 1 in) in length (DS 2), or when new shoots were 2.6 to 5.1 cm (1.0 to 2.0 in) in length (DS 3). At 60 days after pruning (DAP), shoot counts in ternstroemia and 'Sky Pencil' holly treated at DS 3 and 'Snow White' Indian hawthorn treated at DS 2 were greater than those of pruned controls. Shoot counts in 'Jennifer' azalea were not affected by plant developmental stage at the time of CYC application. Relatively minor injury was evident at 60 and 120 DAP in all species except 'Jennifer' azalea, and was most pronounced in ternstroemia and 'Sky Pencil' holly treated at DS 3 and in 'Snow White' Indian hawthorn treated at DS 2. Quality ratings were similarly high for plants of all species and treatments, except in 'Sky Pencil' holly in which quality ratings of plants treated with CYC at DS 1 or DS 3 were higher than those of pruned controls.

Index words: auxin transport inhibitor, plant growth regulator, branching, container nursery production.

Species used in this study: 'Elizabeth Ann' Japanese camellia (*Camellia japonica* L. 'Elizabeth Ann'), 'Snow White' Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl. 'Snow White'), small anisetree (*Illicium parviflorum* Michx. ex Vent.), 'Sky Pencil' holly (*Ilex crenata* Thunb. 'Sky Pencil'), 'Jennifer' azalea (*Rhododendron* L. 'Jennifer'), ternstroemia (*Ternstroemia gymnanthera* Thunb.).

Chemical used in this study: cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid].

Significance to the Nursery Industry

Cyclanilide (CYC), a bioregulator under development by Bayer Environmental Science (Research Triangle Park, NC) as a branching agent for nursery crops, can be highly effective in stimulating lateral shoot growth of fruit trees (2, 3) and several woody ornamental shrubs (4, 5) without pruning and could therefore become a valuable resource for expediting the production of quality nursery crops. However, in a recent study that utilized overwintered plant material, quality and marketability was not enhanced, despite CYC-induced branching. In nursery production, pruning is often necessary to correct legginess and establish quality and marketability. Results of studies that evaluated the interaction of pruning and CYC application on the growth of 'Elizabeth Ann' Japanese camellia (*Camellia japonica* 'Elizabeth Ann'), 'Snow White' Indian hawthorn (*Rhaphiolepis indica* 'Snow White'), small anisetree (*Illicium parviflorum*), 'Sky Pencil' holly (*Ilex crenata* 'Sky Pencil'), 'Jennifer' azalea (*Rhododendron* 'Jennifer') and ternstroemia (*Ternstroemia gymnanthera*) indicate that fewer new shoots were likely to develop on plants pruned before CYC application, but plant quality is likely to be higher than when applying CYC to non-pruned plants. However, the higher quality may be more of a result of pruning than of CYC application in many species.

Introduction

Apical dominance, the control that terminal buds exert over lateral buds on a plant stem (1), is regulated by auxin, which diffuses basipetally from terminal buds and inhibits the development of lateral buds (11), often resulting in loose, sparsely branched plants. Therefore, to develop compact, well-branched plants, apical dominance must be disrupted. Most nurserymen accomplish this through the removal of terminal meristems, e.g. pruning which removes apical dominance and stimulates the development of lateral buds into lateral shoots, resulting in well-branched plants. Unfortunately, most woody landscape shrubs require multiple prunings during nursery production to stimulate branching and thereby create full, compact and marketable plants. Although pruning is considered necessary for plant quality, the process removes viable tissue and reduces overall plant size. A minimum of three weeks of active plant growth is lost as a result of each pruning (12) and because plants sold in 3.8 liter (#1) containers have been pruned at least once and plants sold in 11.4 liter (#3) containers have been pruned at least twice (Tom Dodd Nurseries, Semmes, AL, pers. comm.) substantial production time is often added before plants are marketable. The relatively new bioregulator, cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC), promotes branching of fruit trees (2, 3)

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and select woody ornamental shrubs (4, 5) without pruning, possibly by inhibiting auxin transport and thus temporarily disrupting apical dominance (10).

However, while a single foliar spray of 25 to 200 ppm CYC (5) and 3 weekly foliar sprays of 100 to 300 ppm CYC applied to young, actively growing shrubs stimulated branching and enhanced plant quality, three biweekly foliar sprays of 100 to 300 ppm applied to older, overwintered shrubs stimulated branching but did not improve plant shape and overall quality (4). A concept known as 'apical control' refers to physiological factors, such as plant age or stage of development, that supercede apical dominance in the determination of plant branching patterns and therefore overall shape and form of the plant canopy (1). Apical control can influence the relative length and orientation of lateral shoots (1, 14) and, although shoot length and orientation of plants in the biweekly CYC study were not quantified, this concept may explain why increased shoot formation did not enhance overall appearance and quality.

Another possibility is that plant response to CYC is greater if applied to immature, actively growing foliage instead of mature, hardened foliage. Research with the cytokinin, benzyladenine (BA), showed that branching response was generally optimal when BA was applied to actively growing plants, and response declined if applications were made prior to or after a growth flush (6, 7, 9, 13). In another study, applications of 1750 to 3500 ppm BA were applied at 7-day intervals to Eleanor Taber™ and Olivia™ Indian hawthorn, inkberry holly and 'Harbour Dwarf' nandina at three stages of increasing shoot development: When bud break had recently occurred and shoots were just beginning to expand, developmental stage 1 (DS 1); when actively flushing shoots with immature pubescent foliage were present, DS 2; or when shoots were hardening with fully expanded glabrous green foliage, DS 3. Results of this study agreed with previous research: plants in DS 2 formed more shoots in response to BA than plants in DS 1 or DS 3 and new shoot counts increased with increasing BA concentration. Additionally, plants treated at DS 1 and DS 2 incurred foliar injury, but not those treated at DS 3 (8).

Because nursery crops often require pruning to produce well-branched, marketable plants and because optimal stage of plant development for applying CYC following pruning is not known, the overall objective of this study was to investigate the interactive effects of pruning and CYC application on growth of several nursery crops.

Materials and Methods

Three experiments were conducted, one in 2004 and two in 2006, using similar methodology unless otherwise noted. Growth medium was a 7:1 pinebark:sand substrate amended per m^3 (yd^3) with 7.3 kg (16 lb) 16.5N–2.6P–10K (PolyOn 17–6–12, Pursell Industries, Sylacauga, AL), 0.9 kg (1.5 lb) Micromax (The Scotts Company, Marysville, OH) and 3 kg (5 lb) dolomitic limestone. Plants were spaced outdoors, in either full sun or 47% shade, under twice-daily irrigations of approximately 1.3 cm (0.5 in) each. Plants were re-spaced as needed. Treatments were applied using a CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi). A nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), was included at a rate of 0.2%. Dry and wet-bulb temperatures were recorded at treatment and relative humidity was determined from these measurements. Plants were treated under tree shade to reduce possible foliar burn by sun-drying of solutions and to prolong absorption. After a minimum of 6 hours, plants were returned to irrigated growing areas.

Data collection included: counts of new terminal and/or lateral shoots ≥ 1cm (0.4 in) in length; shoot height and width from which a growth index (GI) was calculated

{GI = [(height + widest width + width 90° to widest width) ÷ 3]}; ratings of foliar injury, if applicable; and ratings of overall plant quality. Injury rating (1 = no injury to 5 = necrosis of new foliage) and subjective quality rating (QR) on a 1-5 scale (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable) were determined by the same person for each collection date within each experiment. The significance of main effects and interactions was determined using SAS General Linear Model procedures (SAS Institute, Cary, NC). Orthogonal polynomial contrasts were used for trend analysis, and paired orthogonal contrasts were used to compare pruned vs. non-pruned treatments ($P = 0.05$).

Experiment 1, 2004. This experiment was conducted to determine the effects of CYC, pruning and the combination of the two on the branching of 'Elizabeth Ann' Japanese camellia and small anisetree. A portion of the data on 'Elizabeth Ann' Japanese camellia was previously reported (5) and is included for comparative purposes. On April 9, uniform, unbranched plants of 'Elizabeth Ann' Japanese camellia and small anisetree in 3.8 liter (#1) containers were obtained from Tom Dodd Nurseries in Semmes, AL. 'Elizabeth Ann' camellia, grown under 47% shade cloth, and small anisetree, grown in full sun, were pruned on April 23 by uniformly removing about one-third and three-fourths, respectively, of existing foliage before plants were treated with 0, 50 or 100 ppm CYC. Small anisetree were excessively tall and sparsely branched, if at all, at the beginning of the experiment and were heavily pruned to promote branching low on the main shoot, however pruning removed most of the foliage. Also on April 23, actively growing, non-pruned plants of both species with immature soft shoots were treated with foliar sprays of 0, 25, 50, 100 or 200 ppm CYC. Plants were arranged in a completely randomized design within species and the eight treatments were replicated with 6 single plants each. Dry bulb temperature and relative humidity at the time of application were 20C (68F) and 50%, respectively. An additional CYC application was made to all 'Elizabeth Ann' camellia and to pruned small anisetree on June 23, 60 days after initial treatment, to determine if further stimulation of new shoots would occur. Dry bulb temperature and relative humidity at the time of the second application were 32C (90F) and 67%, respectively. New shoots were counted 30 and 90 days after initial treatment (DAT); shoots counted 30 DAT had matured by 90 DAT and were not recounted. Plant height and width were measured 60 DAT, and plant quality was rated 120 DAT.

Experiment 2, 2006. This experiment was conducted to further elucidate interactive effects of pruning and CYC application. Plants of ternstroemia in 3.8 liter (#1) containers were obtained from Tom Dodd Nurseries on March 10 and plants of 'Sky Pencil' holly and 'Jennifer' azalea in 7.6 liter (#2) containers were obtained from the Alabama Experimental Substation in Mobile on March 16. All plants were placed outdoors in full sun under overhead irrigation. On April 5, ternstroemia and 'Jennifer' azalea were repotted into 11.4 liter (#3) containers using the previously described substrate. On June 9, a single foliar spray of 0, 100 or 200 ppm CYC was applied to non-pruned plants of: ternstroemia averaging 53.1 cm (20.9 in) in height, 'Jennifer' azalea averaging 52.6 cm (20.7 in) in height and 'Sky Pencil' holly averaging 82.7 cm (32.6 in) in height. Also on June 9, a single foliar spray of 0, 100 or 200 ppm CYC was applied to plants of ternstroemia averaging 37.4 cm (14.7 in) in height, 'Jennifer' azalea averaging 35.3 cm (13.9 in) in height and 'Sky Pencil' holly averaging 33.1 cm (13.0 in) in height that had been uniformly pruned just prior to treatment. At the time of treatment, spring growth had hardened and there were few immature shoots on any of the plants. Foliage of non-pruned ternstroemia and 'Jennifer' azalea had formed a rosette at the terminals of long branches, and because of sparse foliage along the branch length, the wood of branches was often visible. Treatments in this 2 × 3 factorial experiment were completely randomized and replicated with 10 single plants. Dry bulb temperature and relative humidity at the time of application ranged from 27 to 28C (80 to 82F) and from 68 to 72%, respectively. New shoots were counted 60 DAT, shoot height and widths were measured and GI was calculated at 60 and 120 DAT, and plants were rated for quality 120 DAT.

Experiment 3, 2006. The objective of this study was to determine how CYC affects branching when applied at defined stages of lateral shoot development following pruning. Between March 10 and March 16, plants of 'Snow White' Indian hawthorn and ternstroemia in 3.8 liter (#1) containers and plants of 'Sky Pencil' holly and 'Jennifer' azalea in 7.6 liter (#2) containers were placed outdoors in full sun under overhead irrigation. All plants except 'Sky Pencil' holly were repotted into #3 containers using the previously described substrate: 'Snow White' hawthorn on March 23 and ternstroemia and 'Jennifer' azalea on April 5. On June 9, plants of 'Snow White' hawthorn averaging 22.4 cm (8.7 in) in height, plants of ternstroemia averaging 33.5 cm (13.1 in) in height, plants of 'Jennifer' azalea averaging 30.0 cm (11.7 in) in height and plants of 'Sky Pencil' holly averaging 33.1 cm (12.9 in) in height, were uniformly pruned: 'Snow White' hawthorn, ternstroemia and 'Jennifer' azalea by one-third, and 'Sky Pencil' holly by one-half. Plants were then treated with 200 ppm CYC either: immediately after pruning, [developmental stage 1 (DS 1)], on June 28 when new shoots were 1.3 to 2.6 cm (0.5 to 1 in) in length (DS 2), or on July 7 when new shoots were 2.6 to 5.1 cm (1.0 to 2.0 in) in length (DS 3). This experiment included a pruned, non-CYC treated control. Treatments were arranged in a completely randomized design within species and replicated with 10 single plants. Dry bulb temperature and relative humidity during each of the 3 treatment dates ranged from: 27 to 28C (80 to 82F) and 68 to 72% on June 09; 27 to 29C (81 to 85F) and 83 to 84% on June 28; and 28 to 29C (82 to 24F) and 84 to 88% on July 7, respectively.

Data, including shoot counts, measurement of height and widths and calculation of GI, were collected based on plant response to treatment; shoot development occurred at different times following treatment, therefore the specific date of data collection varied with each species. Shoots of 'Snow White' hawthorn plants in treatments 1 and 2 (pruned only and DS 1 plants) were counted and plants measured approximately 45 days after pruning (DAP) and shoots of DS 2 and DS 3 plants were counted and plants measured approximately 60 DAP. New shoots of all 'Jennifer' azalea, 'Sky Pencil' holly and ternstroemia were counted and plants measured approximately 60 DAP. Injury to new foliage of treated 'Snow White' hawthorn, 'Sky Pencil' holly and ternstroemia was rated 60 and 120 DAP using a 1 to 5 scale. Injury rating scale differed according to species. 'Snow White' Indian hawthorn rating scale was: 1 = no injury; 2 = slight discoloration of new foliage, slight reddening of leaf margins, no stunting or distortion; 3 = slight to moderate discoloration of new foliage, reddening of leaf margins, slight stunting, cupping and/or twisting; 4 = moderate to severe reddening of new foliage, moderate to severe stunting, twisting and/or folding; 5 = necrosis of new foliage. 'Sky Pencil' holly rating scale was: 1 = no injury; 2 = slight change in shape of new foliage; 3 = slight change in shape of new foliage and mild to moderate discoloration; 4 = change in shape of new foliage and moderate to severe discoloration; 5 = necrosis of new foliage. Ternstroemia rating scale was: 1 = no injury; 2 = slight discoloration of new foliage; 3 = moderate discoloration of new foliage; 4 = moderate to severe discoloration of new foliage, stunting; 5 = necrosis of new leaves. Finally, height and widths of all plants were measured, GI calculated and plant quality rated 120 DAP.

Results and Discussion

Experiment 1, 2004. New shoot formation of non-pruned 'Elizabeth Ann' Japanese camellia was stimulated by all CYC concentrations. At 30 DAT new shoot counts of non-pruned plants showed a linear increase of 116, 182, 216 and 366% relative to the control in response to 25, 50, 100 and 200 ppm CYC, respectively (Table 1). These increased shoot counts are similar to those previously reported with other woody landscape plants following CYC application (4, 5). Although non-CYC treated pruned plants formed 113% more shoots than non-CYC treated non-pruned plants, shoot counts of pruned plants was not affected by CYC concentration. Plants that were pruned before receiving an application of 50 or 100 ppm CYC formed fewer shoots than plants of the corresponding non-pruned treatments (21 and 46% fewer, respectively). At 90 DAT, and 30 days after a second CYC application, new shoot counts of non-pruned plants increased linearly by 256, 186, 627 and 1232% relative to the control in response to CYC concentrations of 25, 50, 100 and 200 ppm, respectively. The generally higher increases in shoot number following the second CYC application reflect the low number of shoots formed on control plants. Shoot formation of pruned plants remained unaffected by CYC at 90 DAT. At 60 days after the first CYC application, heights of non-pruned plants treated with 25 or 50 ppm were equal to or greater than those of non-pruned controls, while heights of non-pruned plants treated with 100 or 200 ppm were less than those of non-pruned controls. By 120 DAT, heights of non-pruned plants were similar among all CYC treatments. Among non-pruned plants, GI of all CYC-treated plants was greater than that of untreated controls at both 60 and 120 DAT, and CYC-treated plants appeared wider, possibly due to increased shoot formation. Height or GI of pruned plants was not affected by CYC treatments at any of the collection dates. Quality ratings of pruned plants treated with 0 or 50 ppm CYC were higher at 120 DAT than those of correspond-

Table 1. Interaction of pruning and cyclanilide application on the growth of two species of woody nursery crops in 2004, expt. 1.

Treatment	Shoot counts[y] 30 DAT	Shoot counts[y] 90 DAT	Height (cm) 60 DAT	Height (cm) 120 DAT	Growth index[x] 60 DAT	Growth index[x] 120 DAT	Quality rating[w] 120 DAT
			'Elizabeth Ann' Japanese camellia[z]				
0 ppm	8.7*[v]	2.2	70.2	82.5	54.6*	57.1	2.0*
25 ppm	18.8	7.8	70.2	88.2	57.3	64.1	2.5
50 ppm	24.5*	6.3	82.3*	89.8*	66.2*	66.3	2.7*
100 ppm	27.5*	16.0	62.3*	74.5*	59.3*	89.9*	3.7*
200 ppm	40.5	29.3	65.7	78.7	65.6	69.0	3.8
Significance[u]	L***	L***	L*	NS	L*	Q*	L***
Pruned[t] control	18.5	0	41.5	55.0	34.9	44.3	3.0
Pruned + 50 ppm	20.2	0	40.5	58.8	36.7	47.2	3.0
Pruned + 100 ppm	18.8	0	39.3	59.0	33.6	49.7	3.0
Significance	NS	NS	NS	NS	NS	NS	NS
			Small anisetree				
0 ppm	18.8*	0	93.8*	114.6	67.6*	91.1*	1.9
25 ppm	57.2	0	83.2	104.5	65.8	89.0	2.4
50 ppm	70.0*	0	82.5*	99.5	65.0*	80.4*	2.9
100 ppm	60.8*	0	68.2*	87.3	58.1*	78.0*	3.2
200 ppm	69.3	0	71.7	89.3	59.3	78.5	3.5
Significance	Q***	NS	Q***	Q**	Q**	Q**	L***
Pruned control	10.3	0	32.5	86.2	27.1	58.2	2.5
Pruned + 50 ppm	10.8	22.3	30.3	72.7	27.5	51.2	3.0
Pruned + 100 ppm	10.8	34.2	31.7	66.7	29.4	53.3	4.5*
Significance	NS	L***	NS	L**	NS	NS	L***

[z]A portion of the data on 'Elizabeth Ann' Japanese camellia was previously reported (5) and is included for comparative purposes.
[y]Total number of terminal and lateral shoots, quantified 30 days after initial treatment (DAT).
[x]Growth index = (height + widest width + width 90° to widest width) ÷ 3, in cm.
[w]Quality rating: 1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable.
[v]Means followed by an asterisk are significantly different from the corresponding means of the pruned treatment.
[u]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), P = 0.01 (**) or P = 0.001 (***).
[t]Plants uniformly pruned to remove terminal shoots, 'Elizabeth Ann' camellia by one-third and small anisetree by three-fourths.

ing non-pruned plants, however quality ratings were highest in non-pruned plants treated with 100 or 200 ppm CYC.

New shoot formation of non-pruned small anisetree at 30 DAT increased by 204, 272, 223 and 269% in response to 25, 50, 100 and 200 ppm CYC, respectively, compared to the control (Table 1). Pruned plants did not respond to CYC at 30 DAT, possibly because most of the foliage was removed by pruning prior to CYC application. However, by 90 DAT, 30 days after a second CYC application to pruned and refoliated plants, plants that received both pruning and CYC had extensive new shoot development, while plants in all other treatments, including pruning alone, had none. Shoot height and GI of non-pruned CYC-treated plants were lower than those of non-pruned controls at both 60 and 120 DAT, which in combination with increased shoot development, gave plants a denser appearance. Other than a linear decrease in height of pruned plants in response to increasing CYC concentration at 120 DAT, 16% with 50 ppm and 23% with 100 ppm, height or GI of pruned plants was not affected by CYC. A reduced height of pruned plants treated with CYC compared to plants only pruned but with similar GI resulted in plants that were fuller and more compact. Quality rating of both pruned and non-pruned plants at 120 DAT increased linearly in response to increased CYC concentration. Non-pruned and pruned plants that received 25 or 50 ppm CYC were considered unmarketable due to a leggy, open appearance. In contrast, non-pruned plants treated with higher CYC rates were dense, compact and attractively shaped, especially those that received a pruning treatment and two applications of 100 ppm CYC.

These results demonstrate that non-pruned small anisetree readily forms new shoots in response to a single CYC application which agrees with a previous study that included other woody nursery crops (5). However, CYC application immediately following pruning did not stimulate new shoot development, possibly due to the removal of most of the foliage by pruning. The positive response to a second CYC application made 60 days after the first application to fully foliated plants suggest that time of CYC application following pruning is a factor in a plant's response to CYC.

Experiment 2, 2006. At 60 DAT the interaction between pruning and CYC application for new shoot production of ternstroemia was significant (Table 2). Compared to untreated plants, new shoots of non-pruned plants increased 76 and 97% in response to 100 and 200 ppm CYC, respectively,

Table 2. Interaction of pruning and cyclanilide on the growth of two species of woody nursery crops in 2006, expt. 2.

	Ternstroemia				'Sky Pencil' holly	
	Shoots counts[z]		Quality rating[y]		Shoot counts	
CYC conc.	Non-pruned	Pruned	Non-pruned	Pruned	Non-pruned	Pruned
0 ppm	67.3	80.0	4.1	4.0	73.4*	111.5
100 ppm	118.5	106.5	3.4*	4.8	193.0*	111.7
200 ppm	132.5*[x]	93.6	3.1*	4.6	288.1*	144.1
Significance[w]	L***	Q*	L**	Q*	L***	L*

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment.

[y]Quality rating: 1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable.

[x]Means followed by an asterisk are significantly different from the corresponding means of the pruned treatment.

[w]Significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), 0.01 (**) or 0.001 (***).

while new shoots of pruned plants increased by 33 and 17% in response to the same CYC concentrations. Less response to CYC from pruned plants compared to non-pruned plants, 29% less when treated with 200 ppm CYC, agrees with results from experiment 1. However, increased branching did not enhance the appearance of non-pruned ternstroemia, as proliferations of new shoots formed distal rosettes on long, spindly branches resulting in an unattractive drooping appearance. This drooping probably contributed to the linear decrease in height (60 and 120 DAT) and GI (120 DAT) in response to increasing CYC concentration (Table 3), although there was no interaction between pruning and CYC application for height or GI at either sampling date. As expected, shoot height and GI of pruned plants at 60 and 120 DAT were lower than those of non-pruned plants (Table 4). Pruned plants were compact and attractively shaped. At 120 DAT, quality rating of non-pruned plants decreased with increasing CYC concentration (Table 2), further reflecting the unattractive appearance of shoot proliferation that formed distal clusters on long branches resulting in a drooping appearance. This differs from CYC-induced shoot formation in cherry trees in which shoots were uniformly distributed around the leader circumference (3). Similar to results with small anisetree in experiment 1, quality rating of plants that were pruned and treated with CYC were higher than those of plants only pruned (Table 2). In addition, quality ratings of pruned plants treated with 100 or 200 ppm CYC were higher than corresponding quality ratings of non-pruned plants.

Table 3. Effects of cyclanilide concentration on the growth of three species of woody nursery crops in 2006, expt. 2.

	Shoot counts[z]	Height (cm)		Growth index[y]		Quality rating[x]
Treatment	60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
Ternstroemia						
0 ppm	—	45.9	61.7	45.5	65.8	—[w]
100 ppm	—	42.6	56.3	45.8	63.9	—
200 ppm	—	42.2	51.2	43.8	60.1	—
Significance[v]	—	L*	L**	NS	L*	—
'Sky Pencil' holly						
0 ppm	—	68.9	79.5	36.6	40.7	3.6
100 ppm	—	67.3	84.6	36.1	42.7	3.7
200 ppm	—	65.4	84.1	36.4	43.1	4.1
Significance	—	NS	NS	NS	L*	L**
'Jennifer' azalea						
0 ppm	361.7	47.4	53.8	50.8	68.0	3.8
100 ppm	395.5	43.1	47.3	47.4	62.3	4.0
200 ppm	465.4	44.1	49.8	48.3	64.0	3.9
Significance	L***	Q*	Q***	Q*	Q**	NS

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index = (height + widest width + width 90° to widest width) ÷ 3, in cm.

[x]Quality rating: 1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable, evaluated 120 DAT.

[w]Dashes indicate an interaction between pruning and cyclanilide concentration; where there were no interactions, means represent concentration across pruning treatments.

[v]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4. Effect of pruning on the growth of three species of woody nursery crops in 2006, expt. 2.

	Shoots[z]		Height				Growth index[y]				Quality rating[x]	
	60 DAT		60 DAT		120 DAT		60 DAT		120 DAT		120 DAT	
Species	P	NP[w]	P	NP	P	NP	P	NP	P	NP	P	NP
Ternstroemia	—[v]	—	37.1	50.0*[u]	53.2	59.6*	38.2	51.8*	57.5	69.0*	—	—
'Sky Pencil' holly	—	—	44.5	89.6*	66.3	99.1*	28.2	44.4*	36.5	47.7*	4.5	3.1*
'Jennifer' azalea	400.1	415.0*	35.3	54.4*	42.9	57.6*	44.9	57.6*	54.7	74.7*	4.7	3.1*

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment (DAT).

[y]Growth index = (height + widest width + width 90° to widest width) ÷ 3, in cm.

[x]Quality rating: 1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable.

[w]Pruned (P) or non-pruned (NP) treatments.

[v]Dashes indicate an interaction between pruning and cyclanilide concentration; where there were no interactions means represent concentration across pruning treatments.

[u]Means followed by an asterisk are significantly different ($P = 0.05$) from the corresponding means of the pruned treatment.

As with ternstroemia, there was an interaction between pruning and CYC application for new shoot formation in 'Sky Pencil' holly at 60 DAT (Table 2). New shoot formation of non-pruned plants increased by 163 and 293% in response to 100 and 200 ppm CYC, respectively, while shoot increases of pruned plants were only 0.2 and 29% in response to 100 and 200 ppm CYC, respectively, again showing reduced shoot formation when CYC was applied to plants that had been pruned. In the absence of CYC, pruned plants formed 52% more shoots than non-pruned plants, evidence of the shoot stimulating effect of pruning on 'Sky Pencil' holly. In contrast, non-pruned plants treated with 100 and 200 ppm CYC formed 73 and 100%, respectively, more new shoots than corresponding pruned plants. GI of non-pruned plants at 120 DAT showed a small linear increase as CYC concentration increased (Table 3), and CYC-treated plants were visibly wider and denser than non-CYC treated plants. However, foliage density was concentrated in the lower half of non-pruned plants, with the top half being loose and open, suggesting that the effects of CYC had dissipated by 120 DAT, a response previously reported (5). Both height and GI at 60 and 120 DAT were lower in the pruned treatments than in the non-pruned treatments (Table 4), but pruned plants were uniform, densely foliated and attractively shaped. Plant quality rating of 'Sky Pencil' holly increased linearly with increasing CYC concentration at 120 DAT (Table 3) and was significantly higher in pruned plants than in non-pruned plants (Table 4).

There were no interactions between pruning and CYC in 'Jennifer' azalea for any of the measured attributes. New shoot formation at 60 DAT increased linearly as CYC concentration increased, 9 and 29% in response to 100 and 200 ppm, respectively (Table 3). New shoots were not evenly distributed along the length of the branches, but concentrated near branch terminals, forming a rosette of foliage, similar to that with ternstroemia. This enhanced the appearance of pruned plants, as the rosettes formed on short, upright stems and foliage coalesced into a full, compact canopy, but in the non-pruned plants rosettes formed distally on long bare stems resulting in an open canopy. Shoot formation on non-pruned CYC-treated 'Jennifer' azalea contrasts with that on cherry trees in which shoots were evenly distributed along the central leader (3). CYC decreased height and GI of all treated plants at both 60 and 120 DAT (Table 3), and all pruned plants had lower heights and GI at both 60 and 120 DAT than non-pruned plants (Table 4). Quality rating at 120 DAT was not affected by CYC rate but was higher in pruned plants than in non-pruned plants due to increased shoot formation on short stems resulting in a full, dense and attractively shaped canopy.

Experiment 3, 2006. 'Sky Pencil' holly showed a linear increase in new shoot formation as the length of developing shoots increased when CYC was applied (Table 5). There was a minimal increase in shoot formation when CYC was applied immediately after pruning (DS 1), however allowing shoots to elongate to 1.3–2.5 cm (0.5–1.0 in) or 2.5–5.1 cm (1.0–2.0 in), DS 2 and DS 3, respectively, stimulated 122 or 183% more shoots, respectively, compared to non-CYC treated controls. This concurs with the results with small anisetree in experiment 1 in which there was no shoot stimulation when CYC was applied immediately after pruning, but a strong linear increase when a second application was made 60 days after pruning (DAP) (Table 1). Plant height at 60 DAP decreased linearly as shoot length at CYC application increased, but height was not affected at 120 DAP. GI was not affected by treatment at either 60 or 120 DAP. A reduction in height without a concomitant reduction in GI of 'Sky Pencil' holly resulted in plants that were wider at the base, a desirable effect in a cultivar often requiring up to three liners per 3.8 liter (#1) container to produce a marketable plant. CYC-treated plants developed smaller, more elliptical-shaped new leaves than controls as early as 45 DAP. However, this was a temporary effect and when plants were rated for injury at 120 DAP, new leaves, except for some on DS 3-treated plants were, appeared normal in size and shape. At this time the effect on appearance of DS 3 treated plants was minimal as indicated by the injury rating. Plants in all treatments were full and compact, possibly due to pruning, and plants that were treated with CYC were wider than non-CYC treated plants, a desirable effect in a typically upright and spindly cultivar which is often too narrow at the base. Plant quality rating at 120 DAP was not impacted by developmental stage at which CYC was applied, however plants treated with CYC at DS 1 or DS 3 had higher quality ratings than those of untreated plants and appeared wider and fuller.

Shoot counts of 'Jennifer' azalea changed quadratically at 60 DAP in response to CYC application at increasingly later shoot developmental stages, with the most new shoots forming on plants treated at DS 1 and the fewest on plants treated

Table 5. Effects of the timing of cyclanilide application following pruning on the growth of two species of woody nursery crops in 2006, expt. 3.

Treatment	Shoot counts[z]	Height (cm)		Growth index[y]		Injury rating[x]		Quality rating[w]
	60 DAP	60 DAP	120 DAP	60 DAP	120 DAP	60 DAP	120 DAP	120 DAP
				'Sky Pencil' holly				
P[v]	50.4	43.0	66.3	27.1	36.7	—	1.0	3.2
DS 1[u]	55.1	42.7	67.7	27.3	37.0	—	1.0	4.5*
DS 2	111.7*[t]	41.6	70.3	27.2	38.5	—	1.0	3.8
DS 3	142.4*	38.0	69.8	25.4*	38.8	—	1.4	4.2*
Significance[s]	L***	L**	NS	NS	NS	—	Q*	NS
				'Jennifer' azalea				
P	305.3	43.5	50.1	49.9	60.7	—	—	4.7
DS 1	361.3	39.4*	45.3*	45.5*	55.5*	—	—	5.0
DS 2	265.2	40.5	45.9	47.2	57.0*	—	—	4.8
DS 3	329.7	40.1	42.0*	47.9	54.8*	—	—	5.0
Significance	Q*	NS	NS	NS	NS	—	—	NS

[z]Total number of terminal and lateral shoots.

[y]Growth index = (height + widest width + width 90° to widest width) ÷ 3, in cm.

[x]Injury rating: 1 = no injury; 5 = necrosis of new growth.

[w]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[v]P = plants were pruned.

[u]DS 1 = plants pruned and immediately sprayed with CYC; DS 2 = plants pruned and sprayed with CYC when new shoots were 1.3–2.5 cm long or 2.5–3.1 cm long (DS 3).

[t]Means followed by an asterisk are significantly different ($P = 0.05$) from the pruned control based on orthogonal contrasts.

[s]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), 0.01 (**) or 0.001 (***).

at DS 2 (Table 5). However, plants in all CYC treatments formed similar numbers of new shoots as pruned controls. Shoot height or GI at either 60 or 120 DAP was not affected by time of CYC application following pruning, however height of DS 1 plants was lower than that of untreated plants at 60 and 120 DAP. GI of DS 1 plants was less than that of non-CYC treated plants at 60 DAP, and GI of all CYC-treated plants was less than that of untreated controls at 120 DAP. All plants were full, compact and of high quality, probably due to pruning. The effects of CYC on 'Jennifer' azalea when applied at different stages of shoot development following pruning were minimal making application to pruned plants unnecessary.

All CYC-treated ternstroemia formed more new shoots at 60 DAP than untreated plants, although differences varied widely (Table 6). Shoot counts were highest in DS 3 plants, 102% greater than those of untreated plants, followed by those of DS 1 plants (38% greater), and lowest in plants treated at DS 2, 10% greater. Shoot height was not affected by specific stage of CYC application at either 60 or 120 DAP, although DS 3 plants were taller than controls at 60 DAP, possibly because of a higher number of new shoots. GI at 60 DAP was highest in DS 1 plants but by 120 DAP treatment effects on GI were not significant. Bronzing of developing foliage was rated at 60 DAP. Symptoms in plants treated at either DS 1 or DS 2 were limited to mild bronzing of new foliage and were similar to those of untreated plants, suggesting the cause was not due to CYC. However, symptoms in DS 3 plants included moderate bronzing of new growth that was more pronounced than on non-CYC treated plants. By 120 DAP, new foliage had matured and symptoms were less noticeable, although still more pronounced in DS 3 plants than in controls. Bronzing in ternstroemia in response to CYC application did not detract from plant appearance and might be considered desirable. Plants in all treatments were full, compact and marketable at 120 DAP and quality ratings were similar, again indicating CYC application to ternstroemia that had previously been pruned was unnecessary.

Branching of 'Snow White' Indian hawthorn increased linearly in response to applying CYC to plants with increasingly longer shoots. In addition, the number of new shoots of from all CYC-treated plants was higher than those from non-CYC treated plants (Table 5). Plants treated at DS 1, DS 2, and DS 3 formed 50, 124, and 106%, respectively, more new shoots than untreated plants. Shoot height and GI at 60 DAP were not affected by treatments, however at 120 DAP, height increased linearly as shoot length increased when CYC was applied, and DS 3 plants were taller than untreated plants. GI of DS 3 plants was higher at 120 DAP when compared to the controls. Plants at all developmental stages were injured by CYC, suggesting that 200 ppm CYC was excessive. At 60 DAP new foliage of DS 1 plants was bronze with a more pronounced reddening of the leaf margins; these symptoms could be considered aesthetically pleasing. However, injury to DS 2 and DS 3 plants included the above symptoms, as well as leaf cupping and stunted new shoot growth. Symptoms were generally less severe at 120 DAP. At this time, DS 1 plants appeared similar to controls. Injury to DS 2 and DS 3 plants was considerably less severe than at 60 DAP, and while leaves were still discolored, they were not stunted or cupped. A similar expression of injury and dissipation of symptoms was reported in Indian hawthorn following multiple CYC applications (4). Although injury was still evident in many treated plants at 120 DAP, symptoms were not unattractive and plant canopies were dense, compact and well-shaped. Plant quality at 120 DAP was similarly high for plants in

Table 6. Effects of the timing of cyclanilide application following pruning on the growth of two species of woody nursery crops in 2006, expt. 3.

	Shoot counts[z]	Height (cm)		Growth index[y]		Injury rating[x]		Quality rating[w]
Treatment	60 DAP	60 DAP	120 DAP	60 DAP	120 DAP	60 DAP	120 DAP	120 DAP
				Ternstroemia				
P[v]	67.8	34.6	57.9	48.4	60.6	1.6	1.1	3.8
DS 1[u]	93.7*[t]	35.8	60.0	58.0*	60.2	2.0	1.6	4.0
DS 2	74.7*	35.9	52.4	51.6	57.9	1.8	1.3	3.9
DS 3	136.8*	39.2*	56.6	43.4	59.8	2.9*	1.9*	4.3
Significance[s]	Q***	NS	NS	L**	NS	Q*	NS	NS
				'Snow White' Indian hawthorn[r]				
P	32.0	24.6	29.4	33.9	46.5	1.0	1.0	4.5
DS 1	47.9*	22.9	28.3	33.8	47.8	2.2*	1.2	4.9
DS 2	71.7*	23.1	31.2	34.7	45.3	3.4*	2.1*	4.4
DS 3	66.0*	22.7	33.3*	35.7	51.0*	3.0*	2.7*	4.7
Significance	L**	NS	L**	NS	Q*	Q***	L***	NS

[z]Total number of terminal and lateral shoots.

[y]Growth index = (height + widest width + width 90° to widest width) ÷ 3, in cm.

[x]Injury rating: 1 = no injury; 5 = necrosis of new growth.

[w]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[v]P = plants were pruned.

[u]DS 1 = plants pruned and immediately sprayed with CYC; DS 2 = plants pruned and sprayed with CYC when new shoots were 1.3–2.5 cm long or 2.5–3.1 cm long (DS 3).

[t]Means followed by an asterisk are significantly different ($P = 0.05$) from the pruned control based on orthogonal contrasts.

[s]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), 0.01 (**) or 0.001 (***).

[r]Shoot counts and first set of shoot height and GI measurements collected based on plant response to treatment; data collected 45 DAP for plants in P and DS 1 and 60 DAP for the remaining treatments.

all treatments indicating CYC application to pruned Indian hawthorn was not beneficial.

Results of our evaluation of the interaction between pruning and CYC application on the growth of woody nursery crops indicate that non-pruned plants form more shoots than pruned plants as a result of CYC application, possibly due to the presence of more foliage that facilitates CYC absorption into the plant. However, CYC-induced shoot formation may occur near branch terminals, as it did in ternstroemia and 'Jennifer' azalea; therefore, if plants are initially leggy, CYC may not enhance plant quality. Plants in this research were generally of higher quality when pruned before CYC application. Optimal time of CYC application following pruning for the stimulation of new shoots varied among species. However, quality ratings were similarly high for pruned plants of all species and treatments, except 'Sky Pencil' holly in which ratings of plants treated at DS 1 or DS 3 were higher than those of pruned controls, suggesting the higher quality may be more of a result of pruning rather than CYC application.

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