Single Cyclanilide Applications Promote Branching of Woody Ornamentals[1]

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Abstract

Single applications of 0 to 200 ppm cyclanilide (CYC), an experimental bioregulator effective in stimulating lateral branching in fruit trees, were applied to the foliage of 19 species or cultivars of woody landscape shrubs over the 2004 and 2005 seasons, 12 of which exhibited increased branching in response to treatment. New shoot increases were concentration and species dependent. Compared to untreated controls at 30 days after treatment (DAT) in 2004, new shoots increased from 14 to 317% across Florida anise, 'Elizabeth Ann' Japanese camellia, 'Nigra' inkberry holly, 'Chinsan' azalea, 'Red Slippers' azalea, 'Watchet' azalea, 'Ellen Huff' oakleaf hydrangea, 'Brandy's Temper' sasanqua camellia, and Eleanor Taber™ Indian hawthorn following CYC application. In 2005, shoot increases at 60 DAT ranged from 32 to 240% across 'Ellen Huff' oakleaf hydrangea, 'Brandy's Temper' sasanqua camellia, Eleanor Taber™ Indian hawthorn, Olivia™ Indian hawthorn, 'Sky Pencil' holly, and 'Foster' holly. Plant size decreased, increased, or was unaffected by increasing CYC concentration. Foliage of 'Ellen Huff' oakleaf hydrangea in 2004 and Eleanor Taber™ and Olivia™ Indian hawthorn in 2005 was injured by CYC application, however symptoms were no longer evident by the end of the growing season. Quality of treated responsive plants at the end of the growing season in 2004, but not in 2005, was usually higher than that of untreated plants and generally increased with increasing CYC concentration.

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

Species used in this study: 'Elizabeth Ann' Japanese camellia (*Camellia japonica* L. 'Elizabeth Ann'); 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* L. 'Brandy's Temper'); spreading yew (*Cephalotaxus harringtonia* C. Koch. 'Prostrata'); leyland cypress (X *Cupressocyparis leylandii* (Dallim. & A.B. Jackson) Dallim.); fragrant daphne (*Daphne odora* Thunb.); 'Ellen Huff' oakleaf hydrangea (*Hydrangea quercifolia* Bartr. 'Ellen Huff'); 'Foster' holly (*Ilex* x *attenuata* Ashe. 'Fosteri'); 'Sky Pencil' holly (*Ilex crenata* Thunb. 'Sky Pencil'); 'Nigra' inkberry holly (*Ilex glabra* (L.) A. Gray 'Nigra'); Florida anise (*Illicium anisatum* L. 'Semmes'); leatherleaf mahonia (*Mahonia bealei* (Fort.) Carr.); 'Harbour Dwarf' nandina (*Nandina domestica* Thunb. 'Harbour Dwarf'); 'Conia' (Olivia™) and 'Conor' (Eleanor Taber™) Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl.); 'Elegans' rhododendron (*Rhododendron* L. 'Elegans'); 'Chinsan' azalea (*Rhododendron* L. 'Chinsan'); 'Red Slippers' azalea (*Rhododendron* L. 'Red Slippers'); 'Watchet' azalea (*Rhododendron* L. 'Watchet'); and ternstroemia (*Ternstroemia gymnanthera* Thunb.).

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

Significance to the Nursery Industry

Woody landscape shrubs often require pruning multiple times during nursery production to develop compact, well-branched plants. However, significant labor costs and loss of plant biomass can lengthen production time and may diminish the benefits of mechanical pruning. Cyclanilide (CYC), an experimental plant growth regulator, has the potential to induce branching without mechanical pruning. Single foliar sprays of 25 to 200 ppm CYC increased lateral branching of 'Elizabeth Ann' Japanese camellia (*Camellia japonica* 'Elizabeth Ann'), 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* 'Brandy's Temper), 'Ellen Huff' oakleaf hydrangea (*Hydrangea quercifolia* 'Ellen Huff'), 'Foster' holly (*Ilex* x *attenuata* 'Fosteri'), 'Sky Pencil' holly (*Ilex crenata* 'Sky Pencil'), 'Nigra' inkberry holly (*Ilex glabra* 'Nigra'), Florida anise (*Illicium anisatum* 'Semmes'), Eleanor Taber™ Indian hawthorn (*Rhaphiolepis indica* Eleanor Taber™), Olivia™ Indian hawthorn (*Rhaphiolepis indica* Olivia™), 'Chinsan' azalea (*Rhododendron* 'Chinsan'), 'Red Slippers' azalea (*Rhododendron* 'Red Slippers'), and 'Watchet' azalea (*Rhododendron* 'Watchet'). With most species, there was no need to apply CYC above 50 or 100 ppm. In general, when a species developed new shoots after treatment with CYC, height and often growth index, a measure of plant volume, were reduced resulting in a denser canopy, but the beneficial effect was often not evident by the end of the growing season. These results suggest CYC may substitute or complement mechanical pruning in these species. However, a single application per growing season may not be enough to maintain branching benefits.

Introduction

The nursery industry contributes over 300 million dollars per year to the annual total of 1.9 billion dollars in revenue generated by Alabama's nursery and landscape industries, e.g., the 'Green Industry' (1). A significant cost associated with production of most nursery crops, especially woody landscape crops, is the costly, time-consuming manual pruning necessary to develop well-branched, marketable plants. Typically, plants sold in 3.8 liter (#1) containers have been pruned at least once during the 18- to 20-month production cycle, while plants in 11.4 liter (#3) containers have been pruned at least three times during the 27- to 32-month production cycle (Tom Dodd Nurseries, Semmes, AL, pers. comm.).

Plant growth regulators have been evaluated as a substitute or supplement to mechanical pruning of woody ornamentals with mixed results. Benzyladenine (BA), a synthetic cytokinin, is believed to release apical dominance by reducing auxin to cytokinin ratios in shoot tips (4). Foliar sprays or media drenches of BA have been shown to promote axillary bud growth in several woody landscape crops (9, 10, 11,

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12, 13), although response varied with species and cultivar (9, 10, 11, 12, 13), plant developmental stage (13), application concentration (9, 10, 11, 12, 13), application number (9, 11, 12) and application interval (11). In addition to branching response, foliar injury ranging from mild to moderate discoloration, cupping, twisting, and/or stunting of new growth occurred in some species, including Olivia™ Indian hawthorn (11, 12, 13), 'Harbour Dwarf' (9, 13), 'Moyer's Red' and 'Firepower' nandina (9) and 'Nigra' inkberry holly (13). However, injury to all species was transient, and symptoms were no longer evident by the end of the growing season.

Thidiazuron (TDZ), a phenylurea cytokinin registered as a cotton defoliant (Dropp 50WP, Aventis CropScience, Research Triangle Park, NC), promoted branching in *Nandina domestica* cultivars with minimal effect on plant size and produced visibly fuller plants than untreated controls (8). However, mild chlorosis of immature foliage occurred following TDZ applications to nandina and several other species (unpublished data).

Despite the potential of BA and TDZ as branching agents for select woody species, neither is EPA registered, thus they are unavailable for commercial use. Currently, dikegulac sodium (Atrimmec, PBI/Gordon, Kansas City, MO) is the only registered chemical branching agent for use on woody ornamentals. However, it also has growth retarding activity (3, 7), making it more useful in landscape settings than in nurseries (2). Recently, cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC) became available for experimental evaluation as a bioregulator of apple trees. Initial information from Bayer suggested CYC may act as a growth retardant (unpublished data). In subsequent work at Washington State University, directed sprays of 25 to 250 ppm CYC were tested for their inhibitory effects on shoot elongation of apple. While small reductions in shoot length occurred, the primary effect was stimulation of lateral shoots on current growth and from spurs on older wood (5). A later study using 50 to 200 ppm CYC on sweet cherry trees yielded similar branching results and slight foliar injury to one tree variety, 'Bing'/Mazzard, from application of 200 ppm CYC (6). Lateral branch induction in both studies occurred after a temporary interruption of apical dominance without long-term growth reduction or damage to the terminal meristem (5, 6). Based on positive results from Elfving's studies, single foliar sprays of CYC were evaluated for their branching effects on several landscape shrub species or cultivars commonly grown in the southeastern United States.

Materials and Methods

Two experiments were conducted at the Paterson Greenhouse and Nursery Complex on Auburn University's campus, one in 2004 and one in 2005 using similar methodology unless otherwise noted. Container substrate was 7:1 pinebark:sand 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 full sun under twice-daily irrigation totaling approximately 2.6 cm (1.0 in), and were not mechanically pruned during the study. Plants were respaced as needed to avoid foliage contact between adjacent plants. Cyclanilide treatments were applied at 0.2 liter/m^2 (equivalent to 2 qt/100 ft^2 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 0.2%. Dry- and wet-bulb temperatures, from which relative humidity was determined, were recorded at treatment. Plants were treated under tree shade to minimize possible foliar burn and to prolong absorption. Plants were returned to irrigated growing areas after a minimum of 6 hours.

Data collection included: shoot height and width from which growth index (GI) was calculated [GI = (height + widest width + width 90° to widest width) ÷ 3], counts of all new terminal and/or lateral shoots ≥1 cm (0.4 in) in length, and ratings of overall plant quality. Quality was subjectively rated (QR) on a 1 to 5 scale (1 = poorly branched, excessive shoot elongation, sparse canopy; 2 = increased canopy density and branching relative to a QR of 1 but too few shoots that were often excessively elongated; 3 = moderate compaction, density and branching; 4 = increased density, branching and compaction relative to a QR of 3; 5 = compact and well-branched with a dense symmetrical canopy) by the same person within each experiment. Plants with ratings of 3 or higher were considered marketable. Data were subjected to an analysis of variance, using the SAS General Linear Model procedure (SAS Institute, Cary, NC) and orthogonal contrasts were used to test linear and quadratic responses to CYC rate at P = 0.05.

2004. Liners of *Daphne odora* (fragrant daphne), *Rhaphiolepis indica* 'Conor' (Eleanor Taber™ Indian hawthorn), *Ilex glabra* 'Nigra' (inkberry holly), *Illicium anisatum* 'Semmes' (Florida anise), *Rhododendron* 'Chinsan', *Rhododendron* 'Red Slippers' and *Rhododendron* 'Watchet' (azalea cultivars), *Hydrangea quercifolia* 'Ellen Huff' (oakleaf hydrangea), *Nandina domestica* 'Harbour Dwarf' (nandina) and *Rhododendron* 'Elegans' (rhododendron) were repotted into 3.8 liter (#1) containers between late March and early April 2004. *Camellia sasanqua* 'Brandy's Temper' (sasanqua camellia) and *Camellia japonica* 'Elizabeth Ann' (Japanese camellia) were repotted from 0.9 liter (qt) into 7.6 liter (#2) containers on April 1, 2004.

Single foliar applications of 0, 25, 50, 100 or 200 ppm CYC were applied to all species, except 'Chinsan' and Watchet' azaleas, Florida anise and 'Brandy's Temper' sasanqua camellia, during the first flush of spring growth on April 23, 2004. Treatments were arranged in a completely randomized design within species and replicated with 5 to 8 plants per treatment. Dry bulb temperature and relative humidity at application ranged from 26 to 29C (79–85F) and from 47 to 57%, respectively. Single foliar applications of the same CYC concentrations were applied to the remaining species on June 22, 2004, at which time the spring growth flush had matured and plants had little, if any, immature foliage. Treatments were arranged in a completely randomized design within species and replicated with 6 to10 plants per treatment. Dry bulb temperature and relative humidity at application ranged from 27 to 30C (81–86F) and from 67 to 76%, respectively. New shoots were counted 30 days after treatment (DAT), shoot height and perpendicular widths from which GI was calculated were measured 60 DAT, and overall plant quality was rated 100 or 120 DAT.

2005. Plants of 'Brandy's Temper' sasanqua camellia, *Ilex* x *attenuata* 'Foster' holly ('Foster' holly), *Ilex crenata* 'Sky

Pencil' ('Sky Pencil' holly), 'Harbour Dwarf' nandina, Eleanor Taber™ Indian hawthorn, *Rhaphiolepis indica* 'Conia' (Olivia™ Indian hawthorn, *Cephalotaxus harringtonia* 'Prostrata' (spreading yew), x *Cupressocyparis leylandii* (leyland cypress) and *Ternstroemia gymnanthera* (ternstroemia) in 3.8 liter (#1) containers were blocked by plant size. Plants of 'Ellen Huff' oakleaf hydrangea and *Mahonia bealei* (leatherleaf mahonia) in 3.8 liter containers (#1) were blocked by plant size and placed outdoors under 47% shade. Between April 15, 2005, and May 17, 2005, single foliar sprays of 0, 50, 100 or 200 ppm CYC were applied to plants arranged in a randomized complete block design within species or cultivar and replicated with 10 plants each. Treatments were applied during the first flush of spring growth when plants were actively growing. Dry bulb temperatures from 25 to 31C (77–88F) and relative humidity from 78 to 96% were present during applications. Treated spreading yew, leyland cypress, leatherleaf mahonia, 'Harbour Dwarf' nandina and ternstroemia lacked visual treatment effects at 60 DAT and thus received an additional CYC application at the same concentrations on July 6, 2005. Some plants were repotted into 11.4 liter (#3) containers, during the study: leyland cypress on July 8, 2005, 'Sky Pencil' and 'Foster' hollies on July 13, 2005, 'Olivia' and 'Eleanor Taber' Indian hawthorns on July 14, 2005, and ternstroemia on July 18, 2005. Data collection included measurement of shoot height and widths, from which GI was calculated, a count of new lateral and/or terminal shoots at 60 DAT and a rating of plant quality at 120 DAT.

Results and Discussion

CYC was applied to 11 species or cultivars of woody ornamental shrubs in 2004, nine of which exhibited increased branching in response to treatment. In 2005, six of 10 species or cultivars exhibited increased branching in response to CYC application. Branching of fragrant daphne and 'Elegans' rhododendron was unaffected by a single foliar CYC application in 2004 (data not shown). There was no treatment-related branching response from spreading yew, leyland cypress, leatherleaf mahonia or ternstroemia in 2005, despite a second CYC application on July 6, 2005 (data not shown). Branching of 'Harbour Dwarf' nandina was unaffected by CYC treatment in both 2004 and 2005 (data not shown). These results concur with fruit tree research in which plant branching response to CYC application varied with species or cultivar, with some plants not responding (5, 6).

Florida anise. At 30 DAT in 2004, shoot counts in Florida anise changed quadratically in response to increasing CYC concentration (Table 1). Compared to those on untreated plants, shoots increased by 26, 48, 47, and 44% following application of 25, 50, 100, and 200 ppm CYC, respectively, suggesting an optimal concentration of 50 to 100 ppm. Shoot height was unaffected by CYC, however GI at 60 DAT increased linearly with increasing CYC concentration, indicating an overall increase in plant width. Generally, internodes of CYC-treated plants appeared shorter than those of untreated plants, giving CYC-treated plants a more compact appearance. Florida anise is naturally a leggy species, and in spite of perceived shortened internodes, plants would have been more marketable if they had been more compact which may explain a lack of treatment effect on plant quality rating.

'Elizabeth Ann' Japanese camellia. New shoot formation in 'Elizabeth Ann' Japanese camellia increased linearly at 30 DAT in 2004 with increasing CYC concentration, ranging from 117% in plants treated with 25 ppm CYC to 367% in plants treated with 200 ppm CYC, compared to non-treated controls (Table 1), indicating that the optimal concentration for branching was at least 200 ppm. Shoot height decreased linearly and GI increased linearly at 60 DAT as CYC concentration increased, indicating a greater width of treated plants. The combination of abundant lateral shoot growth on shorter plants gave treated plants a fuller, more compact appearance than untreated plants, resulting in an increase in quality rating at 120 DAT as CYC concentration increased.

Hollies. The three holly cultivars tested all responded positively to CYC. Compared to those of untreated controls, shoot counts increased 36 to 117% in treated 'Nigra' inkberry holly (Table 1), 48 to 63% in 'Sky Pencil' holly, and 105 to116% in Foster holly (Table 2) as CYC concentration increased. In

Table 1. Effects of single foliar applications of cyclanilide (CYC) on the growth of three species of woody nursery crops in 2004.

CYC conc. (ppm)	Shoot counts[z]	Height (cm)	Growth index[y]	Quality rating[x]
	30 DAT	60 DAT	60 DAT	120 DAT
	Florida anise			
0	11.7	51.3	52.6	2.8
25	14.7	50.0	53.8	3.1
50	17.3	54.0	60.7	3.3
100	17.2	51.5	57.9	3.3
200	16.8	54.0	61.7	3.3
	Q*[w]	NS	L*	NS
	'Elizabeth Ann' Japanese camellia			
0	8.7	70.2	54.6	2.0
25	18.8	70.2	57.3	2.5
50	24.5	82.3	66.2	2.7
100	27.5	62.3	59.3	3.7
200	40.5	65.7	65.6	3.8
	L***	L*	L*	L***
	'Nigra' inkberry holly			
0	26.7	49.3	43.6	2.0
25	41.5	48.3	44.9	3.0
50	54.7	51.0	47.5	3.7
100	55.7	45.0	44.4	3.7
200	57.8	46.0	45.3	4.5
	L***	NS	NS	L***

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

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

[x]Quality rating:1 = poorly branched, excessive shoot elongation, sparse canopy; 2 = increased canopy density and branching relative to a QR of 1 but too few shoots that were often excessively elongated; 3 = moderate compaction, density and branching; 4 = increased density, branching and compaction relative to a QR of 3; 5 = compact and well-branched with a dense symmetrical canopy, evaluated 100 or 120 DAT.

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

Table 2. **Effects of single foliar applications of cyclanilide on the growth of three species of woody nursery crops in 2005.**

CYC conc. (ppm)	Shoot counts[z] 60 DAT	Height (cm) 60 DAT	Growth index[y] 60 DAT	Quality rating[x] 120 DAT
	Olivia™ Indian hawthorn			
0	17.7	23.3	32.6	3.2
50	32.8	22.3	33.4	3.8
100	36.8	23.8	31.7	4.0
200	25.8	25.8	31.3	4.2
	Q***[w]	Q**	NS	NS
	'Sky Pencil' holly			
0	34.3	34.3	19.7	2.0
50	50.8	29.8	18.8	2.8
100	54.3	31.8	18.5	3.7
200	55.8	31.2	18.3	3.0
	L*	Q*	L*	Q*
	'Foster' holly			
0	26.7	49.3	25.3	2.5
50	54.7	51.0	27.8	3.0
100	55.7	45.0	24.8	2.7
200	57.8	46.0	24.3	3.2
	L***	NS	L*	NS

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

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

[x]Quality rating:1 = poorly branched, excessive shoot elongation, sparse canopy; 2 = increased canopy density and branching relative to a QR of 1 but too few shoots that were often excessively elongated; 3 = moderate compaction, density and branching; 4 = increased density, branching and compaction relative to a QR of 3; 5 = compact and well-branched with a dense symmetrical canopy, evaluated 100 or 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at P = 0.05 (*), P = 0.0 (**), or P = 0.001 (***).

Table 3. **Effects of single foliar applications of cyclanilide (CYC) on the growth of three azalea cultivars in 2004.**

CYC conc. (ppm)	Shoot counts[z] 30 DAT	Height (cm) 60 DAT	Growth index[y] 60 DAT	Quality rating[x] 100 DAT
	'Chinsan' azalea			
0	17.7	16.8	22.9	2.6
25	27.8	15.5	19.6	3.1
50	29.2	15.5	19.6	3.5
100	32.5	11.3	15.2	2.8
200	35.4	13.0	18.6	4.1
	L**	L*	L**	L**
	'Red Slippers' azalea			
0	8.6	23.8	22.1	2.0
25	11.8	23.4	21.3	2.6
50	9.8	21.2	20.1	2.8
100	12.4	21.0	20.0	3.2
200	14.8	16.8	19.9	4.3
	L**	L***	NS	L***
	'Watchet' azalea			
0	7.8	26.8	30.0	—
25	18.3	22.8	25.0	—
50	21.7	22.5	24.7	—
100	29.2	22.7	27.0	—
200	29.2	23.0	26.5	—
	L***	NS	NS	Not rated

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

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

[x]Quality rating:1 = poorly branched, excessive shoot elongation, sparse canopy; 2 = increased canopy density and branching relative to a QR of 1 but too few shoots that were often excessively elongated; 3 = moderate compaction, density and branching; 4 = increased density, branching and compaction relative to a QR of 3; 5 = compact and well-branched with a dense symmetrical canopy, evaluated 100 or 120 DAT.

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

general, there were only minor increases in shoot production when CYC was applied at concentrations above 50 ppm.

CYC effects on plant height, GI, and quality rating varied with cultivar. Neither shoot height nor GI of 'Nigra' inkberry holly was affected by treatment at 60 DAT. Compared to that of untreated controls, plant quality rating at 120 DAT increased by 50 to 125% as CYC concentration increased from 25 to 200 ppm, reflecting the denser, fuller appearance of treated plants (Table 1). In contrast, height and GI of 'Sky Pencil' holly and GI of 'Foster' holly, but not height, decreased slightly as CYC concentration increased (Table 2). Quality rating of 'Sky Pencil' holly at 120 DAT peaked in response to 100 ppm CYC, whereas that of 'Foster' holly was unaffected by treatment, reflecting the short-lived effect of single applications of CYC on this cultivar.

Azaleas. The three azalea cultivars tested in 2004 increased new shoot formation in response to CYC application. Compared to those of untreated controls, shoot counts of treated 'Chinsan' azalea increased by 57 to 100% in response to CYC application, whereas shoot counts of 'Red Slippers' and 'Watchet' azaleas increased by 14 to 72% and 135 to 274%, respectively (Table 3). Shoot height and GI of the three azalea cultivars either decreased or was unaffected by increased CYC concentrations. Treated 'Chinsan' and 'Red Slippers' azaleas were visibly fuller and more compact than controls; these changes in growth habit were reflected in linear increases in quality rating at 100 DAT with increasing CYC concentration.. In contrast, treated plants of 'Watchet' azalea were similar in appearance to untreated plants at 100 DAT and were not rated for quality. Treatment effects on 'Watchet' azalea contrast with those on 'Chinsan' and 'Red Slippers' azaleas, and reflect cultivar differences in response to plant growth regulators (9, 12), including CYC (6).

'Ellen Huff' oakleaf hydrangea. At 30 DAT in 2004, shoot counts of 'Ellen Huff' oakleaf hydrangea showed a linear increase of 39 to 72% as CYC concentration increased (Table 4). Increased shoot production at 60 DAT in 2005 was also linear, increasing 119 to 240% as concentration increased

(Table 2). GI decreased linearly in response to increasing CYC concentration at 60 DAT in 2004 but was not affected by treatments at 60 DAT in 2005. Shoot height was unaffected by treatments in either year. Plants treated with 25, 50 or 100 ppm CYC displayed mild foliar bronzing, primarily of immature leaves, while plants treated with 200 ppm CYC displayed moderate foliar discoloration and mild stunting/distortion of new growth. Symptoms were still present, though less severe at 60 DAT, but were no longer evident by 120 DAT. In contrast, there was no injury to oakleaf hydrangea in 2005 following application of the same CYC concentrations. Quality ratings were unaffected by treatment in both 2004 and 2005 and were relatively low due to the loose, leggy appearance of plants in all treatments, suggesting that hand pruning may be necessary to produce high quality oakleaf hydrangea.

'Brandy's Temper' sasanqua camellia. Similar to 'Elizabeth Ann' Japanese camellia, CYC increased shoot production of 'Brandy's Temper' sasanqua camellia. At 30 DAT in 2004, shoot counts increased linearly with increasing CYC concentration, from 50% in plants treated with 25 ppm CYC to 125% in plants treated with 200 ppm CYC (Table 4). A similar linear increase in shoots counts occurred at 60 DAT in 2005, ranging from 32% with 50 ppm CYC to 68% with 200 ppm CYC (Table 2). Higher percent increases in shoot counts of 'Brandy's Temper' camellia in 2004 than in 2005 reflect the relatively low increases in untreated controls, 17 in 2004 versus 42 in 2005, when younger, more sparsely branched plants were used. In absolute terms, shoot increases relative to untreated controls were similar, 8 to 21 in 2004 and 13 to 28 in 2005. Shoot height at 60 DAT in 2004 decreased linearly by 10 to 21% with increasing CYC concentrations. In contrast, shoot height changed quadratically in response to increasing CYC at 60 DAT in 2005, increasing 11% following application of 50 ppm CYC but decreasing 16% in response to 200 ppm CYC. In both years, treated plants generally appeared fuller and more compact than untreated controls. However, quality rating at 100 DAT in 2004 indicated a higher quality only in plants treated with 100 ppm CYC. At 120 DAT in 2005, quality rating increased linearly with increasing CYC concentration, by 14, 17, and 35% in response to 50, 100 and 200 ppm CYC, respectively, when compared to untreated plants. Quality rating was noticeably higher in 2005 than in 2004, regardless of treatment, possibly due to starting the experiment with more established plants.

Indian hawthorns. Both Eleanor Taber™ and Olivia™ Indian hawthorn formed new shoots in response to CYC appli-

Table 4. Effects of single foliar applications of cyclanilide on the growth of three species of woody nursery crops in 2004 and 2005.

	2004					2005			
CYC conc. (ppm)	**Shoot counts[z]**	**Height (cm)**	**Growth index[y]**	**Quality rating[x]**	**CYC conc. (ppm)**	**Shoot counts[z]**	**Height (cm)**	**Growth index[y]**	**Quality rating[x]**
	30 DAT	**60 DAT**	**60 DAT**	**120 DAT**		**30 DAT**	**60 DAT**	**60 DAT**	**120 DAT**
'Ellen Huff' oakleaf hydrangea									
0	1.8	50.9	55.5	2.2	0	4.7	58.2	55.5	1.6
25	2.5	50.9	53.7	2.1	50	10.3	42.8	49.8	2.2
50	2.4	38.9	51.2	2.1	100	15.5	42.8	47.7	2.5
100	2.8	35.6	42.2	2.0	200	16.0	42.2	45.6	2.9
200	3.1	39.6	47.0	2.1					
	L*[w]	NS	L*	NS		L***	NS	NS	NS
'Brandy's Temper' sasanqua camellia									
0	16.9	62.9	72.6	2.7	0	41.7	78.0	71.9	3.7
25	25.4	56.3	67.5	2.8	50	55.0	87.5	74.5	4.2
50	27.2	56.2	70.4	2.8	100	68.2	78.5	73.4	4.3
100	42.1	54.7	70.6	3.5	200	70.2	65.3	70.3	5.0
200	38.0	49.5	65.2	2.5					
	L***	L*	NS	Q*		L**	Q*	NS	L***
Eleanor Taber™ Indian hawthorn									
0	13.5	25.8	39.4	3.1	0	12.8	19.5	27.6	3.2
25	42.1	24.6	38.5	3.9	50	21.8	19.7	27.6	3.5
50	43.4	23.1	36.7	3.8	100	30.0	19.3	28.2	3.5
100	46.7	25.3	36.3	3.6	200	36.8	18.3	27.6	3.3
200	54.9	25.0	36.7	4.6					
	L***	NS	L*	L*		L***	NS	NS	NS

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

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

[x]Quality rating: 1 = poorly branched, excessive shoot elongation, sparse canopy; 2 = increased canopy density and branching relative to a QR of 1 but too few shoots that were often excessively elongated; 3 = moderate compaction, density and branching; 4 = increased density, branching and compaction relative to a QR of 3; 5 = compact and well-branched with a dense symmetrical canopy, evaluated 100 or 120 DAT.

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

cation. Shoot counts of Eleanor Taber™ Indian hawthorn increased linearly with increasing CYC concentration at 30 DAT in 2004 (Table 4), from 212% with 50 ppm CYC to 306% with 200 ppm CYC. A similar linear trend occurred with Eleanor Taber™ Indian hawthorn at 60 DAT in 2005; new shoot counts ranged from 70 to 187% greater in plants treated with 50 to 200 ppm CYC compared to untreated controls. These shoot increases combined with a lack of treatment effect on height or GI at 60 DAT in either 2004 or 2005, except for a slight decrease in GI in 2005 with increasing CYC concentration, resulted in plants that were visibly denser and more compact than controls. Although not present in 2004, mild to moderate foliar injury, ranging from slight reddening to stunting and/or cupping of new growth, was evident on treated plants by 45 DAT in 2005. Injury was not rated, but symptoms appeared to increase in severity as CYC concentration increased. Symptoms were no longer evident by the end of the growing season, ~220 DAT. Quality rating increased linearly with increasing CYC concentration at 120 DAT in 2004, but, due to foliar injury, was insignificant in 2005.

Olivia™ Indian hawthorn was included in the 2005 experiment because it naturally tends to have a looser, more open growth habit than does Eleanor Taber™ and thus requires more frequent pruning during production to produce marketable plants. In contrast to the linear increase in shoots in Eleanor Tabor™, shoot formation in Olivia™ changed quadratically at 60 DAT in response to increasing CYC concentrations (Table 2), with 100 ppm CYC being optimal. Shoot height was minimally affected by CYC treatments while GI was unaffected. Similar to Eleanor Taber™ in 2005, quality rating of Olivia™ was not affected by CYC treatment due to foliar injury that was evident by 45 DAT. Symptoms, which were not quantified, appeared to increase in severity as CYC concentration increased and ranged from slight yellowing of new foliage to more severe yellowing, stunting or cupping of new foliage. Injury was transient and no longer evident by 220 DAT.

Results of these studies indicate that single applications of CYC can promote branching of numerous woody landscape species during production, including Florida anise, 'Elizabeth Ann' Japanese camellia, 'Nigra' inkberry holly, 'Chinsan', 'Red Slippers' and 'Watchet' azaleas, 'Ellen Huff' oakleaf hydrangea, 'Brandy's Temper' sasanqua camellia, Eleanor Taber™ and Olivia™ Indian hawthorn and 'Sky Pencil' and 'Foster' holly. However, CYC at the concentration tested did not promote branching of fragrant daphne, 'Elegans' rhododendron, spreading yew, leatherleaf mahonia, ternstroemia or 'Harbour Dwarf' nandina, even following a second application to the latter four species. These results are similar to those of previous studies using TDZ and BA on woody ornamental shrubs (9, 10, 11) and CYC on fruit trees (5, 6), in which response varied with species, cultivar and application concentration.

Optimal CYC concentration for shoot formation varied with species and cultivar. Generally, there was little practical benefit in applying CYC at a concentration greater than 50 or 100 ppm to Florida anise, holly, Indian hawthorn, azalea, oakleaf hydrangea, or sasanqua camellia. In contrast, 'Elizabeth Ann' camellia formed the most shoots and had the highest quality rating when treated with 200 ppm CYC. Plant height was either reduced or unaffected by CYC, whereas GI increased, decreased or was unaffected. In several species, including common and sasanqua camellias treated plants were noticeably wider than controls. Many treated plants appeared fuller and more densely compact than untreated controls. Foliar injury was noted in three species: slight discoloration to moderate stunting of new foliage of 'Ellen Huff' oakleaf hydrangea in 2004, but not 2005, and mild to moderate yellowing and/or stunting of new growth of Eleanor Taber™ and Olivia™ Indian hawthorn in 2005, but plants outgrew injury symptoms by the end of the growing season.

Quality rating of responsive species was generally higher in treated plants when compared to untreated plants at 100 or 120 DAT in 2004, but were generally insignificant at 120 DAT in 2005 due to foliar injury (Indian hawthorn cultivars), a dissipation of the branching response or the maturation of CYC-induced shoots resulting in most treated plants appearing similar to untreated plants when data were collected at 120 DAT. Plants used in the 2005 tests were well established and often well-branched before treatment while the majority of plants used in 2004 were younger and more sparsely branched. Regardless, several species outgrew the effects of single CYC applications in both 2004 and 2005 by the end of the growing season, approximately 220 DAT, suggesting that methods that will increase the duration of plant response to CYC, while minimizing the potential for foliar injury, should be examined.

Literature Cited

1. Alabama Agricultural Experiment Station. 2005. State's green industry grows to $1.9 billion. http://www.ag.auburn.edu/aaes/webpress/2005/green.htm. (Last accessed October 2006).

2. Banko, T.J. and M.A. Stefani. 1996. Growth response of large, established shrubs to Cutless, Atrimmec and Trim-Cut. J. Environ. Hort. 14:177–180.

3. Bruner, L.L., G.J. Keever, J.R. Kessler, Jr., and C.H. Gilliam. 2002. Atrimmec suppresses shoot length and promotes branching of *Lonicera* x *heckrottii* 'Goldflame' (Goldflame honeysuckle). J. Environ. Hort. 20:73–76.

4. Cline, M.G. 1998. Apical dominance. Bot. Rev. 57:318–358.

5. Elfving, D.C. and D.B. Visser. 2005. Cyclanilide induces lateral branching in apple trees. HortScience 40:119–122.

6. Elfving, D.C. and D.B. Visser. 2006. Cyclanilide induces lateral branching in sweet cherry trees. HortScience 41:149–153.

7. Fain, G.B., C.H. Gilliam, and G.J. Keever. 2001. Response of *Lagerstroemia* x 'Tuscarora' to Pistill and Atrimmec. J. Environ. Hort. 19:149–152.

8. Keever, G.J. and D.A. Findley. 2001. Thidiazuron increases shoot formation in nandina. J. Environ. Hort. 20:24–28.

9. Keever, G.J. and T.A. Morrison. 2003. Multiple benzyladenine applications increase new shoot formation in nandina. J. Environ. Hort. 21:144–147.

10. Keever, G.J. and W.J. Foster. 1990. Chemically induced branching of woody landscape plants. J. Environ. Hort. 8:78–82.

11. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2004. BA-induced shoot formation in Indian hawthorn. J. Environ. Hort. 22:71–74.

12. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. BA application frequency and concentration effects on two Indian hawthorn cultivars. J. Environ. Hort. 23:37–41.

13. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. Developmental stage influences plant response to benzyladenine. J. Environ. Hort. 23:149–152.