Multiple Cyclanilide Applications Promote Branching of Woody Ornamentals[1]

A.S. Holland[2], G.J. Keever[3], J.R. Kessler, Jr.[4], and F. Dane[3]
Department of Horticulture
Auburn University, AL 36849

Abstract

Multiple weekly or biweekly applications of 0, 100, 200 or 300 ppm cyclanilide (CYC), a bioregulator effective in stimulating branching of apple and cherry trees and select woody ornamental shrubs, were applied foliarly to eight species or cultivars of woody landscape shrubs, five of which showed increased branching in response to treatment. Shoot number increases were concentration and species dependent, and compared to untreated controls, branching at 60 days after first treatment (DAFT) with three weekly applications of 100 to 300 ppm CYC in 2005 increased from 1400 to 1900% in 'Brandy's Temper' sasanqua camellia, 114 to 175% in 'Sky Pencil' holly, 385 to 458% in 'Foster' holly, 166 to 335% in Eleanor Taber™ Indian hawthorn, and 1885 to 2230% in 'Olivia'™ Indian hawthorn. In 2006, branching 60 DAFT with three biweekly applications of 100 to 300 ppm CYC increased 34 to 73% in 'Foster' holly, 268 to 413% in Eleanor Taber™ Indian hawthorn, and 2540 to 4440% in Olivia™ Indian hawthorn. Plant size often decreased with increasing CYC concentration, but not in all species or cultivars. Injury to new foliage of 'Brandy's Temper' camellia and 'Sky Pencil' and 'Foster' holly occurred in 2005, and to new foliage of Eleanor Taber™ and Olivia™ Indian hawthorn in both 2005 and 2006, however symptoms were transient and no longer evident by 120 DAFT. Quality of treated responsive plants at 120 DAFT was usually higher than that of untreated plants, and CYC-induced treatment effects generally persisted until the end of the growing season.

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

Species used in this study: 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* Thunb. 'Brandy's Temper'); spreading yew (*Cephalotaxus harringtonia* C. Koch. 'Prostrata'); 'Foster' holly (*Ilex ×attenuata* Ashe.'Fosteri'); 'Sky Pencil' holly (*Ilex crenata* Thunb.'Sky Pencil'); 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.).

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

Significance to the Nursery Industry

Woody ornamental shrubs often require multiple prunings during nursery production to develop compact, well-branched plants. However, significant labor costs and loss of plant biomass that can lengthen production time are incurred with mechanical pruning. Single foliar sprays of 25 to 200 ppm cyclanilide (CYC), an experimental plant growth regulator (Bayer Environmental Science, Research Triangle Park, NC) increased shoot formation, promoted plant compaction and thus enhanced overall appearance of 12 species or cultivars of woody landscape shrubs in a previous study. However, these effects were transitory and treated plants appeared similar to untreated plants by the end of the growing season (~220 days after treatment). Three weekly foliar sprays of 100, 200, or 300 ppm CYC increased branching, promoted compaction and enhanced quality of 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* 'Brandy's Temper'), 'Foster' (*Ilex ×attenuata* 'Fosteri') and 'Sky Pencil' hollies (*Ilex crenata* 'Sky Pencil'), and Eleanor Taber™ (*Rhaphiolepis indica* 'Conor') and Olivia™ (*Rhaphiolepis indica* 'Conia') Indian hawthorns, and effects were more persistent than single foliar applications. However, foliar injury occurred to all species, although symptoms were transitory and plants outgrew injury by 120 days after first treatment (DAFT). Symptoms generally increased from slight discoloration of new foliage to moderate to severe discoloration and/or stunting of new foliage as CYC concentrations increased from 100 to 300 ppm. While all CYC concentrations promoted branching and compaction, injury was minimal with 100 ppm foliar sprays. These results suggest that multiple CYC applications increase plant branching, compaction and overall quality more effectively than single applications, however injury, although transitory, was severe enough to discourage weekly or biweekly applications at concentrations above 100 ppm.

Introduction

Most woody shrubs utilized in southeastern U.S. landscapes require costly, time-consuming manual pruning during nursery production to be well-branched and marketable. Plant growth regulators that may offer a substitute to manual pruning, such as benzyladenine (BA) and thidiazuron (TDZ), have been tested for branching effects on select woody species with mixed results (5, 6, 7, 8, 9, 10) and neither is EPA registered for commercial nursery use. Dikegulac sodium (Atrimmec, PBI/Gordon, Kansas City, MO), the only registered chemical branching agent for use on woody ornamentals, has growth retarding activity (1, 4) and is widely used in commercial landscape maintenance, but not in nurseries.

Recently, the bioregulator cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC) became available for testing as a growth retardant for apple trees. Concentrations of 25 to 250 ppm CYC generally promoted slight reductions in shoot length but mainly stimulated lateral shoot formation on both current and previous season's growth without injury (2). In a subsequent study with sweet cherry, 50 to 200 ppm CYC promoted branching, although 'Bing'/Mazzard sweet cherry tree was injured by 200 ppm CYC (3). Lateral branch induction in both apple and sweet

[1]Received for publication March 21, 2007; in revised form May 24, 2007.
[2]Graduate Assistant. <amanda.holland@bayercropscience.com>.
[3]Professor. <keevegj@auburn.edu> and <danefen@auburn.edu>, respectively.
[4]Associate Professor. <kessljr@auburn.edu>.

cherry trees appeared to result from a temporary interruption of apical dominance without long-term growth reduction or damage to the terminal meristem (2, 3).

In a subsequent study testing the effectiveness of single foliar applications of 25 to 200 ppm CYC on branching of 19 commonly produced woody ornamental shrubs, 12 shrubs showed increased branching in response to treatment (unpublished data). In general, shoot numbers of responsive species increased linearly with increasing CYC concentration and treated plants were full and densely compact. Foliar injury symptoms generally increased in severity as CYC concentration increased in three species: New foliage of treated 'Ellen Huff' oakleaf hydrangea (*Hydrangea quercifolia* 'Ellen Huff') displayed interveinal chlorosis, and new foliage of Eleanor Taber™ and Olivia™ Indian hawthorn displayed mild to moderate yellowing and/or stunting. However, injury was transient and symptoms were no longer evident by the end of the growing season.

Unfortunately, enhancement of plant compaction and quality was also transient in several species and cultivars, and maturation of the single flush of CYC-induced growth resulted in treated plants similar in appearance to untreated plants by the end of the growing season. In research with BA, multiple applications to species responsive to single applications were more effective in stimulating shoot formation. For example, shoot formation in 'Harbour Dwarf' nandina was minimally affected by a single application of up to 2500 ppm BA (6, 7), but shoot numbers increased almost five- and six-fold with five weekly applications of 2500 ppm and 5000 ppm BA, respectively, compared to a single application (6).

Additionally, multiple BA applications promoted shoot formation in species unresponsive to single BA applications. Indian hawthorn did not show increases in new shoot numbers in response to single BA applications of up to 1000 ppm (7), whereas four applications of 2500 ppm BA increased branching of Olivia™ Indian hawthorn liners by seven shoots per plant when compared to none for controls at 45 days after last treatment (9). Our objective was to determine the effects of multiple CYC applications on branching of five species responsive to single CYC applications, as well as three previously unresponsive species.

Materials and Methods

Experiment 1. In September or October 2004, liners of 'Foster' (*Ilex ×attenuata* 'Fosteri') and 'Sky Pencil' (*Ilex crenata* 'Sky Pencil') hollies, Olivia™ and Eleanor Taber™ Indian hawthorns (*Rhaphiolepis indica* 'Conia' and 'Conor'), 'Harbour Dwarf' nandina (*Nandina domestica* 'Harbour Dwarf'), spreading yew (*Cephalotaxus harringtonia* 'Prostrata'), and leatherleaf mahonia (*Mahonia bealei*) were repotted into 3.8 liter (#1) containers of a 7:1 pinebark:sand growth medium amended per m^3 (yd^3) with 4.7 kg (8 lb) 17N–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. 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* 'Brandy's Temper') grown in 3.8 liter (#1) containers were repotted into 11.4 liter (#3) containers of the same amended medium at the same time. All plants were spaced 41 cm (16 in) on center outdoors in full sun, except spreading yew and mahonia which were spaced under 47% shade, and irrigated twice-daily during the growing season with approximately 1.3 cm (0.5 in) water per irrigation cycle. Plants were respaced as needed to avoid canopies overlapping. In March 2005, 3.8 liter (#1) and 11.4 liter (#3) containers were topdressed with 40 g (1.4 oz) and 70 g (2.5 oz), respectively, of 17N–2.6P–10K (PolyOn 17–6–12). In July 2005, hawthorns, hollies, and nandina were repotted into the previously described amended substrate, except 7.3 kg (16 lb) of 17N–2.6P–10K (PolyOn 17–6–12) was incorporated.

Beginning on June 10, 2005, three weekly applications of 0, 100, 200, or 300 ppm CYC were made to 'Brandy's Temper' camellia, 59.0 to 65.5 cm (23.2 to 25.8 in) in height; 'Foster' holly, 19.2 to 26.2 cm (7.6 to 10.3 in) in height; 'Sky Pencil' holly, 22.7 to 26.2 cm (8.9 to 10.3 in) in height; Olivia™ Indian hawthorn, 23.0 to 23.6 cm (9.1 to 9.3 in) in height; and Eleanor Taber™ Indian hawthorn, 21.1 to 22.3 cm (8.3 to 8.8 in) in height, all five of which increased new shoot formation in response to single CYC applications (unpublished data). Also beginning on June 10, five weekly applications of the same CYC concentrations were made to three species unresponsive to single CYC applications (unpublished data): 'Harbour Dwarf' nandina, 12.7 to 13.7 cm (5.0 to 5.4 in) in height; spreading yew, 9.3 to 13.5 cm (3.7 to 5.3 in) in height; and leatherleaf mahonia, 12.0 to 14.0 cm (4.7 to 5.5 in) in height. At first application, plants had completed their spring growth flush and had little, if any, immature foliage. Weekly treatments were stopped when plants exhibited visible increased shoot development, injury, or five applications had been made.

Treatments were applied at 0.2 liter/m^2 (equivalent to 2 qt/100 ft^2) and 138 kPa (20 psi) using a CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA). A nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), was included at the rate of 0.2%. Dry and wet-bulb temperatures were recorded at treatment and relative humidity was determined from these measurements. Dry bulb temperature and relative humidity at application ranged from 26 to 32C (79 to 90F) and from 62 to 83%, respectively. Plants were treated under tree shade to reduce possible foliar burn from CYC and to prolong absorption. After a minimum of 6 hours, plants were returned to irrigated growing areas.

Shoot height and widths from which growth index (GI) was calculated [GI = (height + widest width + width 90° to widest width) ÷ 3] were recorded at 60 and 120 days after first treatment (DAFT); new terminal and/or lateral shoots = 1 cm (0.4 in) in length were counted at 60 DAFT; and plant quality was rated at 120 DAFT 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. Treatments were arranged in a randomized complete block design within species or cultivars and replicated with 10 plants per treatment, except 'Brandy's Temper' camellia which was replicated with 6 plants per treatment. 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 $P = 0.05$.

Experiment 2. Methodology in the second experiment was similar to that of the first experiment, unless noted. 'Foster' holly, and Eleanor Taber™ and Olivia™ Indian hawthorns in 3.8 liter (#1) containers were maintained in a nursery area in full sun under overhead irrigation and covered with perforated white polyethylene sheets during periods of forecasted freezing temperatures. On March 20, 2006, plants were repotted into 11.4 liter (#3) containers using the previously described amended substrate with 7.3 kg (16 lb) of 17N–2.6P–10K (PolyOn 17–6–12) incorporated. Beginning on June 5, three biweekly applications of 0, 100, 200, or 300 ppm CYC were made to plants of 'Foster' holly, 80.0 to 86.2 cm (31.5 to 33.9 in) in height; Eleanor Taber™ Indian hawthorn, 29.5 to 33.5 cm (11.6 to 13.2 in) in height; and Olivia™ Indian hawthorn, 29.5 to 35.5 cm (11.6 to 14.0 in) in height. Dry bulb temperature and relative humidity during application ranged from 29 to 32C (84 to 90F) and from 59 to 92%, respectively.

New terminal and/or lateral shoots ≥ 1 cm (0.4 in) in length were recorded at 60 DAFT; shoot height and widths from which growth index (GI) was calculated and plant injury, if present, were determined at 60 and 120 DAFT (1 = no injury; 2 = slight bronzing or reddening of new foliage; 3 = slight to moderate bronzing or reddening, slight to moderate stunting of new foliage; 4 = moderate to severe bronzing or reddening, moderate to severe stunting of new foliage; 5 = necrosis of new foliage); and plant quality was rated at 120 DAFT. Hollies were arranged in a randomized complete block design and replicated with 10 single plants per treatment. The two hawthorn cultivars were placed in a factorial arrangement (CYC × cv) and replicated with five single plants per cultivar; main effects and interactions were determined using analysis of variance (ANOVA).

Results and Discussion

'Harbour Dwarf' nandina, spreading yew and leatherleaf mahonia that did not previously form new shoots in response to single CYC applications (unpublished data) were likewise unresponsive to multiple applications of CYC, even after five weekly applications (data not shown). However, species that previously formed new shoots in response to single CYC applications, 'Brandy's Temper' sasanqua camellia, 'Sky Pencil' and 'Foster' hollies, and Eleanor Taber™ and Olivia™ Indian hawthorns (unpublished data), also formed new shoots in response to three weekly or biweekly CYC applications.

'Brandy's Temper' sasanqua camellia. In 2005, attractive reddening of new foliage of all treated 'Brandy's Temper' camellia, regardless of specific CYC concentration, was noted 21 DAFT and persisted until approximately 90 DAFT. Dramatic differences in the number of new shoots were evident at 60 DAFT. Controls had fewer than three new shoots per plant, while plants treated with 100 ppm CYC had almost 17 times as many new shoots (Table 1). Increased concentrations of CYC resulted in little (300 ppm) or no (200 ppm) further increases in shoot counts, suggesting an optimal concentration of no higher than 100 ppm when applied weekly for a total of three applications. Shoot height was not affected by CYC treatment at either 60 or 120 DAFT. However, GI of treated plants increased linearly with increasing CYC concentrations at 60 DAFT and plants were noticeably wider, probably from the formation of numerous lateral shoots; shoots also were more pendulous than those on untreated plants. CYC-induced changes in plant form of 'Brandy's Temper' camellia were still evident at 120 DAFT and GI of treated plants remained higher than that of untreated plants, especially those receiving 100 ppm or 200 ppm CYC.

Table 1. Effects of three weekly foliar applications of cyclanilide on the growth of five species of woody nursery crops in 2005.

CYC conc. (ppm)	Shoot no.[z]	Height (cm)		Growth index[y]		Quality rating[x]
	60 DAFT[w]	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
	'Brandy's Temper' camellia					
0	2.7	82.8	82.5	81.8	87.8	4.2
100	43.2	89.3	87.8	90.2	93.0	4.3
200	40.5	84.0	92.0	92.0	96.2	4.3
300	54.0	85.5	98.2	98.2	89.4	4.5
Sign.[v]	Q*	NS	NS	L**	Q*	NS
	'Sky Pencil' holly					
0	32.1	55.9	66.6	26.6	32.7	3.2
100	69.0	41.9	60.6	29.9	32.2	3.7
200	88.3	40.3	60.9	22.0	32.1	3.6
300	85.7	40.2	58.5	22.5	30.9	4.0
Sign.	Q***	Q*	L*	Q*	NS	L**
	'Foster' holly					
0	18.1	44.2	66.6	44.8	65.4	3.0
100	87.7	25.8	48.4	29.4	55.2	3.2
200	98.9	25.3	50.0	28.3	53.1	3.8
300	101.0	25.3	47.4	31.6	53.5	3.9
Sign.	Q***	Q***	L*	Q***	Q*	L***
	Eleanor Taber™ Indian hawthorn					
0	15.4	24.9	32.1	35.2	46.5	3.5
100	40.9	23.2	29.4	32.6	42.7	4.2
200	55.0	22.4	29.7	32.6	41.6	4.3
300	67.0	22.8	27.9	32.9	41.6	4.7
Sign.	L***	L*	L**	Q*	L***	L***
	Olivia™ Indian hawthorn					
0	2.0	24.5	27.6	34.2	42.6	2.1
100	39.7	20.9	27.9	31.5	39.3	3.7
200	46.6	21.4	26.3	31.1	39.2	3.1
300	43.0	21.6	28.7	31.3	39.7	3.5
Sign.	Q***	NS	NS	NS	NS	Q**

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

[y]Growth index = [(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 120 DAFT.

[w]DAFT = days after first treatment.

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

Multiple CYC applications visually delayed flowering of treated 'Brandy's Temper' camellia, which did not occur with single CYC applications (unpublished data). Flower buds of untreated plants began to open in mid-October, those of plants treated with 100 ppm CYC approximately one week later, followed by plants treated with 200 ppm CYC and finishing with plants treated with 300 ppm CYC in the middle of November, although no data were collected. Number of flowers per plant and flower morphology were not visually affected. Quality rating was not affected by CYC treatment; all plants of 'Brandy's Temper' camellia were of high quality and considered marketable.

'*Sky Pencil' holly.* 'Sky Pencil' holly can be costly to produce because its slender growth habit often necessitates up to three liners per one gallon container to give the illusion of one marketable plant. Therefore, our primary objective was to increase plant width. In 2005, shoot number at 60 DAFT changed quadratically in response to increasing CYC concentration (Table 1). Increased shoot counts relative to the control treatment were 115, 175 and 166% following three weekly applications of 100, 200, and 300 ppm CYC, respectively. CYC-treated plants were 25% (100 ppm) to 28% (200 ppm and 300 ppm) shorter than controls at 60 DAFT, while at 120 DAFT plants previously treated with CYC were 9 to 12% shorter than controls. GI of plants previously treated with 100 ppm CYC was 12% greater than that of controls at 60 DAFT, while GI of plants treated with 200 or 300 ppm CYC was ~16% lower than that of controls. By 120 DAFT, GI was similar among plants in all treatments. A reduction in height following treatment with CYC coupled with an increase or no change in GI reflects increased plant width and visibly more dense and compact plants. A change in the shape of newly formed leaves was noted 21 DAFT; treated plants formed new leaves that were noticeably more elongated than untreated controls, however these symptoms were no longer evident at 90 DAFT. Plant quality at 120 DAFT increased linearly with increasing CYC concentration and treated plants were considered more marketable than controls because of their greater width and compactness.

'Foster' holly. Shoot number of 'Foster' holly increased in response to both weekly and biweekly CYC treatments, although the response varied. In 2005, shoot formation in 'Foster' holly changed quadratically following three weekly applications, with plants treated with 100, 200, and 300 ppm CYC producing 385, 446 and 458% more shoots, respectively, than untreated plants at 60 DAFT (Table 1). Shoot numbers increased linearly at 60 DAFT in 2006 following three biweekly applications, with plants treated with 100 and 300 ppm CYC forming 34 and 74% more shoots than untreated controls (Table 2). Lower percent shoot increases in 2006 reflect the much higher shoot counts of controls in 2006, 18.1 vs. 77.1, and probably are related to differences in initial plant sizes. In 2005, plants in 3.8 liter (#1) containers averaged 21.2 cm (8.3 in) in height and had a mean GI of 23.9 cm (9.4 in) at first treatment, whereas, plants used in the second experiment that were grown in 3.8 liter (#1) con-

Table 2. Effects of three biweekly applications of cyclanilide on the growth of two species of woody nursery crops in 2006.

CYC conc. (ppm)	Shoot no.[z]	Height (cm)		Growth index[y]		Injury rating[x]	Quality rating[w]
	60 DAFT[v]	60 DAFT	120 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT
	'Foster' holly						
0	77.1	94.0	111.0	71.2	79.3	—	2.7
100	103.1	83.2	115.9	67.3	82.5	—	2.8
200	133.8	87.6	118.0	65.6	78.6	—	3.4
300	133.3	84.0	104.9	69.3	77.1	—	3.6
Sign.[u]	L**	NS	NS	NS	NS	—	L*
	Indian hawthorn[t]						
0	—	36.6	49.2	39.6	55.5	1.0	3.0
100	—	36.8	51.2	39.0	55.8	2.3	3.0
200	—	34.3	47.1	38.5	53.4	3.1	3.5
300	—	36.4	49.2	42.6	56.4	3.6	3.1
Sign.	—	NS	NS	NS	NS	L***	NS

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

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

[x]Injury rating: 1 = no injury; 2 = slight bronzing or reddening of new foliage; 3 = moderate bronzing or reddening; 4 = moderate to severe bronzing or reddening, moderate to severe stunting; 5 = necrosis.

[w]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 120 DAFT.

[v]DAFT = days after first treatment.

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

[t]CYC × cultivar nonsignificant ($P = 0.05$) for all attributes except shoot counts, hence data for the two cultivars were pooled. Shoot counts for each cultivar are presented in the body of the paper.

tainers in 2005, over-wintered, and repotted into 11.4 (#3) containers before first treatment, averaged 82.6 cm (32.5 in) in height and had a mean GI of 62.7 cm (24.7 in). Regardless of the magnitude of effect in the two experiments, treated plants formed more shoots than untreated plants in response to both weekly and biweekly CYC applications.

Shoots of CYC-treated 'Foster' hollies were about 43% shorter than those of controls at 60 DAFT in 2005 and 25 to 29% shorter at 120 DAFT. Reductions in GI relative to those of controls ranged from 30 to 37% at 60 DAFT and from 16 to 19% at 120 DAFT. Increased shoot counts and reduced height and GI reflect the visibly altered growth habit of CYC-treated plants; untreated plants were open, strongly upright, and sparsely branched, while treated plants were compact, densely branched, and about as wide as they were tall. The change in form of treated plants persisted throughout the 2005 growing season and, although not quantified, into spring of 2006 before they resumed a more upright growth habit. Neither plant height nor GI was affected by CYC at either 60 or 120 DAFT in 2006, possibly due to the treatment of larger plants than in 2005. Mild discoloration of leaves and reddening of leaf margins developed on new growth of treated plants by 21 DAFT in 2005, although symptoms were no longer evident by 90 DAFT. No discoloration of the new foliage occurred to CYC-treated plants in 2006. Plant quality in both 2005 and 2006 increased linearly with increasing CYC concentration, and treated plants were fuller and more uniformly shaped than untreated plants.

Indian hawthorn. In 2005, shoot number of Eleanor Taber™ Indian hawthorn increased linearly with increasing CYC concentration at 60 DAFT (Table 1). Compared to controls, plants receiving three weekly applications of 100, 200, and 300 ppm CYC formed 165, 257, and 335%, respectively, more new shoots than controls. Under normal production conditions, Olivia™ does not readily branch and therefore requires more frequent pruning to develop a marketable plant than does Eleanor Taber™ (8, 9). This condition was exemplified by the low shoot counts of Olivia™ control plants with an average of two shoots per plant at 60 DAFT in 2005. However, treated plants readily developed new shoots in response to three weekly CYC applications, forming between 40 and 47 new shoots per plant.

In 2006, there was an interaction between cultivar and CYC treatment for shoot counts, but not for any other data. Shoot counts of Eleanor Taber™ changed quadratically in response to increasing CYC concentration at 60 DAFT; plants formed 19, 97.5, 86, and 70 shoots following three bi-weekly applications of 0, 100, 200, and 300 ppm CYC, respectively. These increases of 268 to 413% indicate an optimal concentration for new shoot formation of less than 200 ppm. In 2006, shoot counts of Olivia™ at 60 DAFT increased linearly as CYC concentration increased, from two new shoots on untreated plants to 53, 65 and 91 new shoots on plants treated with 100, 200 and 300 ppm CYC, respectively.

In 2005, shoot height of Eleanor Taber™ at both 60 and 120 DAFT and GI at 120 DAFT decreased linearly with increasing CYC concentration, whereas GI at 60 DAFT changed quadratically. Reductions in shoot height and GI relative to those of control plants were about 10 and 7%, respectively, at 60 DAFT and 13 and 11%, respectively, at 120 DAFT with no visible differences in size of plants treated with the different CYC concentrations. Neither shoot height nor GI of Olivia™ in 2005 or Indian hawthorn in 2006 (Table 2) was affected by CYC treatment. A reduction in size of Eleanor Taber™ in response to CYC and a lack of effect of CYC on size of Olivia™ coupled with prolific shoot formation in both cultivars gave plants a densely compact appearance.

Transient injury to new foliage of treated Indian hawthorn occurred in both 2005 and 2006. Symptoms, which generally increased with CYC concentration, were similar in both years and ranged from mild to moderate burgundy foliage coloration to stunting, cupping and twisting of leaves. Symptoms were evident approximately 21 DAFT in 2005 and approximately 60 DAFT in 2006, suggesting weekly applications injured plants more quickly than biweekly applications. Injury was not quantified in 2005, but symptoms were no longer evident by the end of the growing season. In 2006 injury ratings at 60 DAFT increased linearly with increasing CYC concentration. Ratings at 120 DAFT were not significant (data not shown), indicating injury symptoms had dissipated.

In 2005, quality rating of Eleanor Taber™ at 120 DAFT increased linearly by up to 34% as CYC concentration increased. Quality rating of Olivia™ at 120 DAFT in 2005 changed quadratically in response to increased CYC concentration. Quality rating was highest for Olivia™ treated with 100 ppm CYC, averaging 76% higher than that of controls. All treated Olivia™ were full, compact and considered marketable, while untreated plants were sparsely branched, loose and open. Plant quality in 2006 was not affected by CYC treatment, possibly due to the use of older, overwintered plants that were initially misshapen. Therefore, despite CYC-induced shoot formation, plant canopies were not well-shaped, suggesting that pruning may be necessary if plants are initially not compact.

In research with the cytokinin BA, multiple applications promoted shoot formation in species unresponsive to single applications (7, 9), as well as greater shoot formation in previously responsive species (6, 7). Neither a single CYC application (unpublished data) nor five weekly CYC applications affected branching in spreading yew, leatherleaf mahonia, or 'Harbour Dwarf' nandina. However, multiple weekly and/or biweekly CYC applications made to species responsive to single CYC applications: 'Brandy's Temper' sasanqua camellia, 'Sky Pencil' and 'Foster' hollies and Eleanor Taber™ and Olivia™ Indian hawthorns, promoted shoot formation and compact, well-branched canopies, thus enhancing overall plant quality. Plants treated with a single CYC application generally responded with a linear increase in new shoot counts as CYC concentration increased (unpublished data), while plants treated with multiple CYC applications generally responded with a quadratic change. New shoot counts following multiple applications of 100 ppm CYC generally increased dramatically compared to untreated controls, however further increases in response to 200 ppm or 300 ppm CYC were usually small, and were actually lower in 'Sky Pencil' holly and Olivia™ Indian hawthorn treated with 300 ppm CYC compared to those treated with 200 ppm CYC.

'Brandy's Temper' sasanqua camellia, 'Sky Pencil' and 'Foster' hollies, and Eleanor Taber™ and Olivia™ Indian hawthorns responded to three weekly or biweekly CYC applications by forming more new shoots than untreated controls. Overall, the beneficial effects of multiple CYC applications on plant size, compaction and quality rating were evident in most species and cultivars at both 60 and 120 DAFT, and even to the end of the growing season, although this was not quantified. This contrasts with unpublished results using single applications in which CYC reduced height, GI, or both at 60 days after treatment (DAT) but by 120 DAT plants had often outgrown any effects of CYC on growth or compactness.

Unfortunately, transient foliar injury often accompanied increased longevity of plant compactness and quality. In 2005, injury to all species was evident 21 DAFT with 3 weekly CYC applications. In 2006, injury to Indian hawthorn cultivars was evident 45 DAFT with three biweekly CYC applications. The effect of CYC on foliage of 'Brandy's Temper' camellia was limited to attractive reddening of new growth. In 'Sky Pencil' holly new leaves were more elongated than normal, while new foliage of 'Foster' holly was mildly discolored and leaf margins turned an attractive red. Injury to Indian hawthorn cultivars initially detracted from plant appearance. Injury from three applications of 100 and 200 ppm CYC was limited to mild and moderate discoloration, respectively, of new foliage, while 300 ppm CYC caused moderate to severe discoloration and stunting, cupping and/or twisting of new foliage. Although plants outgrew injury symptoms by 120 DAFT, results of this study suggest little benefit in multiple CYC applications at concentrations above 100 ppm. Three applications of 100 ppm CYC promoted new shoot production, plant compaction and enhanced quality with minimal injury. Future research with multiple CYC applications warrants the investigation of concentrations lower than 100 ppm to determine if branching, compaction and quality can be promoted without plant injury.

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