Application Interval and Concentration Affect Nursery Crop Response to Cyclanilide[1]

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Abstract

Cyclanilide (CYC) is a bioregulator that promotes the development of lateral shoots in ornamental and fruit tree crops, potentially reducing the need for mechanical pruning during nursery production. In 2006, three foliar applications of 200 ppm CYC applied at a 1, 2, or 3 week application interval increased shoot counts of 'Diana' sasanqua camellia, 'Sky Pencil' holly, and 'Snow White' Indian hawthorn when compared to pruned and unpruned controls. However, application interval had no effect on shoots counts in holly or camellia and minimal effect in Indian hawthorn. Foliar injury to Indian hawthorn was severe, regardless of application interval. In 2007, three applications of 50 or 100 ppm CYC were applied at a 1, 3, or 6 week interval to 'Sky Pencil' holly and 'Snow White' Indian hawthorn. At 120 to 150 days after initial treatment (DAIT), shoot counts in both species increased with application interval, and all CYC-treated plants formed more new shoots than controls. Transitory injury to new growth of Indian hawthorn, although not quantified, appeared to increase as application interval decreased. At 120 DAIT foliar injury was no longer evident in Indian hawthorn. At 180 DAIT quality rating of both cultivars increased with CYC application interval and was greater than that of controls, and CYC-treated plants were visibly more dense and compact.

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

Species used in this study: 'Snow White' Indian hawthorn [*Rhaphiolepis indica* (L.) Lindl. 'Snow White'], 'Sky Pencil' holly (*Ilex crenata* Thunb. 'Sky Pencil'), 'Diana' sasanqua camellia (*Camellia sasanqua* Thunb. 'Diana').

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

Significance to the Nursery Industry

In an earlier study, single foliar applications of cyclanilide (CYC) promoted terminal and lateral shoot development and improved quality of responsive nursery crops (5). However, increased shoot production was often limited to the growth flush subsequent to application. In a later study, 3 weekly or biweekly CYC applications increased new shoot development; however, transitory injury decreased marketability of sensitive species (6). In the current study, three applications of 200 ppm CYC increased shoot counts of 'Snow White' Indian hawthorn (*Rhaphiolepis indica* 'Snow White'), 'Sky Pencil' holly (*Ilex crenata* 'Sky Pencil'), and 'Diana' sasanqua camellia (*Camellia sasanqua* 'Diana') compared to pruned and unpruned controls. The effect of application interval (1, 2, or 3 week) on shoot counts was minimal. 'Diana' sasanqua camellia or 'Sky Pencil' holly were not injured by CYC application; however, injury was severe enough to 'Snow White' Indian hawthorn to discourage three applications of 200 ppm CYC at intervals tested. Three applications of 50 or 100 ppm CYC were made at 1, 3, and 6 week intervals to 'Snow White' Indian hawthorn and 'Sky Pencil' holly. Under these conditions, branching response was most persistent, injury was most transient, and end-of-season plant quality was highest when CYC was applied over the longer interval.

Introduction

Apical dominance, the suppression of lateral bud outgrowth by auxins produced in shoot apices, is broken when terminal shoots are removed (2, 10). This process has practical implications during the production of most woody ornamental shrubs that usually require multiple mechanical prunings to promote the dense canopy preferred by consumers (2, 11). However, pruning is labor intensive and the tissue removed during pruning increases production time by at least 3 weeks per pruning (11). Exogenous application of cytokinins or plant growth regulators (PGRs) with cytokinin-like activity also can reduce apical dominance by counteracting auxins (1, 7, 8, 9). Cyclanilide (CYC), a plant growth regulator (PGR) currently marketed in combination with ethephon as the cotton (*Gossypium* spp.) defoliant Finish®, acts as an auxin transport inhibitor, temporarily interrupting apical dominance and allowing latent lateral buds to mature (10). In research conducted on apple (*Malus* sp.) and sweet cherry (*Prunus* sp.), single foliar applications of 25 to 200 ppm CYC promoted lateral shoot development on current and previous season's wood but did not affect long-term leaf or meristem morphology or impair their function (3, 4).

The prospect of promoting lateral shoot development without affecting long term morphology made CYC an ideal candidate for application to ornamental species. During initial testing, single foliar applications of 25 to 200 ppm CYC increased lateral shoot counts on 12 of 19 ornamental species tested (5). Foliar injury, if it occurred, was transitory and plant quality of treated plants was generally higher than controls; however, increased lateral shoot production was often limited to the growth flush subsequent to treatment and plants often appeared similar to controls 6 to 7 months after treatment (5). In a later study, up to five weekly or biweekly applications of 100 to 300 ppm CYC were applied to species responsive or unresponsive to single spray applications (6). Three applications increased shoot counts and usually improved quality of 'Sky Pencil' and 'Foster' hollies (*Ilex* spp.), Olivia™ and Eleanor Taber™ Indian hawthorns, and 'Brandy's Temper' camellia when compared to controls.

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Species that did not respond to single applications were not responsive to five applications of CYC. New shoot counts in 'Sky Pencil' holly increased 115 to 175%, and plant width and quality increased with increasing CYC concentration. The increased width of CYC treated holly is particularly desirable during production because it could reduce the number of liners per pot necessary to produce a marketable plant. New leaves of CYC-treated holly were slightly smaller and more elongated than those of controls; however, negative effects on marketability were minimal. Similarly, Indian hawthorn readily formed new shoots in response to 3 weekly or biweekly applications of 100 to 300 ppm CYC. However, 3 weekly applications of 300 ppm CYC and 3 biweekly applications of 200 or 300 ppm CYC caused transitory foliar injury that initially reduced plant marketability (5). The objective of this study was to further investigate the interactive effects of CYC concentration and application interval on new shoot development and foliar injury in species that differ in sensitivity to CYC. Our overall goal was to develop a production strategy using CYC as a season-long branching agent while minimizing foliar injury that could impact marketability.

Materials and Methods

2006. Uniform plants of 'Snow White' Indian hawthorn, 'Diana' sasanqua camellia and 'Sky Pencil' holly in 3.8 liter (#1) containers were obtained from Tom Dodd Nurseries in Semmes, AL. 'Diana' sasanqua camellia was repotted on March 27, 2006, into 11.4 liter (#3) containers using a 7:1 pinebark:sand medium (by vol) amended per m^3 (yd^3) with 9.5 kg (16 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. Plants were spaced on an unshaded nursery pad with overhead irrigation applied twice daily, totaling about 2.5 cm (1.0 in). On May 30, plants received the first of three foliar applications of 200 ppm CYC (Bayer Environmental Science, Research Triangle Park, NC) with subsequent applications made at a 1, 2, or 3 week application interval. The CYC solutions included a nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), at 0.2% by volume, and were applied using a CO_2 sprayer with a flat-spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi) in 0.2 liter·m^{-2} (equivalent to 2 qt·100 ft^{-2}). At the time of first application, shoot tissue from the first growth flush had matured and very few immature shoots were present. Treatments were applied in the shade to minimize phytotoxicity and maximize absorption. After a minimum of 6 hours, plants were returned to the nursery pad. An untreated control and a pruned treatment were included for comparison; about one third of the canopy was removed from pruned controls on the day of initial CYC application. Treatments were completely randomized and replicated with 10 single plants. Dry and wet-bulb temperatures were recorded at application times and relative humidity determined. Temperatures ranged from 26.7C (80F) to 29.4C (85F) and relative humidity ranged from 21 to 39%.

New lateral and terminal shoots ≥ 1 cm (0.4 in) in length were counted at 60 days after initial treatment (DAIT). At 60 and 120 DAIT, plant height and widths [mean W = (widest width + width 90° to widest width) ÷ 2], and a plant injury rating, if applicable, were recorded. The injury rating scale for 'Snow White' Indian hawthorn was: 1 = no injury; 2 = slight reddening of new growth; 3 = slight to moderate reddening of new growth, slight cupping, twisting and/or stunting of new foliage; 4 = moderate to severe reddening of new foliage, moderate to severe stunting, twisting, and/or cupping; and 5 = necrosis of new foliage. Quality of sasanqua camellia, but not the other species, was rated at 120 DAIT using a 1 to 5 scale (1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact). Data analysis included an analysis of variance using PROC GLM (SAS version 9.1.3, SAS Institute, Cary, NC). Single degree of freedom orthogonal contrasts were used to test linear and quadratic trends, and paired comparison contrasts were used to compare specific treatments at $\alpha = 0.05$.

2007. The experiment was repeated in 2007 using similar methodology unless otherwise noted. Uniform liners of 'Snow White' Indian hawthorn in 50-cell flats and 'Sky Pencil' holly in 32-cell flats were repotted into 1.1 liter (1 qt) pots on November 27, 2006, and January 23, 2007, respectively, using the previously described substrate. Plants were overwintered outdoors in full sun and were covered with perforated white polyethylene sheets when freezing temperatures were forecast. On May 17, 2007, plants received the first of three applications of 50 or 100 ppm CYC with subsequent applications made at a 1, 3, or 6 week interval. Temperatures ranged from 25.6 to 31.1C (78 to 88F) and relative humidity ranged from 21 to 75%. An untreated control, but not a pruned control, was included for comparison. Treatments were arranged in a completely randomized design and replicated with eight ('Sky Pencil' holly) or 10 ('Snow White' Indian hawthorn) single plants.

Data collection included new shoot counts at 60 and 120 to 150 DAIT, plant height and widths at 60 and 180 DAIT, and a quality rating (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable) at 180 DAIT. Shoot counts were taken over a period of time (120–150 DAIT) due to differences among treatments in timing of new shoot development.

Results and Discussion

'Diana' sasanqua camellia. In 2006, 'Diana' sasanqua camellia was not visibly injured by three applications of 200 ppm CYC. At 60 DAIT, pruned controls formed 75% more new shoots than unpruned controls, while plants treated with CYC formed more new shoots than pruned and unpruned controls (Table 1). Plants treated with CYC at 1, 2, and 3 week intervals formed 57, 52 and 48% more shoots, respectively, than pruned controls and 175, 167, and 158% more shoots, respectively, than unpruned controls. The application interval did not influence shoot production. At 60 DAIT, height and width of pruned controls were less than those of unpruned controls and CYC treated plants. When compared to unpruned controls at 60 DAIT, height of CYC treated plants was only suppressed when treated at a 3 week interval, while width was not affected by CYC application. At 120 DAIT, plants in all treatments were similar in height, regardless of pruning regiment or CYC application. However, pruned plants were narrower than unpruned controls and plants treated at the 3 week application interval. Quality rating of unpruned controls was higher than pruned controls due to a larger canopy that was relatively dense. Quality ratings of CYC treated plants were higher than that of unpruned controls, except when CYC was applied at a 3 week interval and higher than that of pruned controls. These results support the

Table 1. Effects of cyclanilide application interval on growth of 'Diana' sasanqua camellia in 2006.

	Shoot counts[z]	Plant height (cm)		Plant width[y] (cm)		Quality rating[x]
Treatment	60 DAIT	60 DAIT	120 DAIT	60 DAIT	120 DAIT	120 DAIT
Control	24	61.8	63.1	43.6	46.0	3.7
Pruned	41	46.9	61.3	37.6	39.6	3.2
1-week[w]	65	58.6	61.3	44.9	43.7	4.0
2-week	64	58.8	61.2	43.9	44.3	4.0
3-week	62	55.0	55.5	46.7	46.6	3.9
C vs. P[v]	**[u]	***	NS	*	*	*
C vs. 1-week	***	NS	NS	NS	NS	*
C vs. 2-week	***	NS	NS	NS	NS	*
C vs. 3-week	***	*	NS	NS	NS	NS
P vs.1-week	***	***	NS	**	NS	***
P vs. 2-week	***	***	NS	*	NS	***
P vs. 3-week	**	**	NS	***	**	***

[z]Total number of actively growing terminal and lateral shoots quantified 60 days after initial treatment (DAIT).

[y]Average width = (widest width + width 90° to widest width) ÷ 2.

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

[w]Three applications of 200 ppm CYC made at a 1, 2, or 3 week interval.

[v]C = control plants; P = pruned plants.

[u]Nonsignificant (NS) or significant contrasts at α = 0.05 (*), 0.01 (**), or 0.001(***).

findings of Holland et al. (6) in which 3 weekly applications of 100 to 300 ppm CYC increased shoot formation in 'Alabama Beauty' sasanqua camellia. In contrast to results with 'Diana' sasanqua camellia, transitory foliar injury, limited to attractive reddening of new growth, persisted until 90 DAIT in 'Alabama Beauty' sasanqua camellia and quality ratings of CYC treated plants and controls were similar at 120 DAIT. Results from this study indicate that three applications of at least 100 ppm CYC at a 1, 2, or 3 week interval increase shoot production and promote the formation of a more dense and compact canopy in sasanqua camellia. CYC application to slow growing species, like sasanqua camellias, could increase terminal and lateral shoot production without the reduction in plant size associated with pruning, decreasing time to sale, and increasing the number of shoots available for propagation.

'Sky Pencil' holly. At 60 DAIT in 2006, pruned 'Sky Pencil' holly had formed 160% more new shoots than unpruned controls. New shoot counts of CYC treated holly were greater than those of unpruned and pruned controls, regardless of CYC application interval (Table 2). CYC treated plants formed 77, 100, and 92% more new shoots than pruned controls and 360, 420 and 400% more shoots than unpruned controls when applied at 1, 2, and 3 week application intervals, respectively. At 60 DAIT, height of CYC treated plants

Table 2. Effects of cyclanilide application interval on growth of 'Sky Pencil' holly in 2006.

	Shoot counts[z]	Plant height (cm)		Plant width[y] (cm)	
Treatment	60 DAIT	60 DAIT	120 DAIT	60 DAIT	120 DAIT
Control	5	37.2	44.0	7.9	9.5
Pruned	13	22.6	33.7	8.4	9.6
1-week[x]	23	20.2	30.0	8.3	10.0
2-week	26	25.4	47.5	8.4	10.4
3-week	25	24.9	29.4	7.8	9.2
C vs. P[w]	*[v]	***	NS	NS	NS
C vs. 1-week	***	***	*	NS	NS
C vs. 2-week	***	***	NS	NS	NS
C vs. 3-week	***	***	*	NS	NS
P vs.1-week	**	NS	NS	NS	NS
P vs. 2-week	***	NS	*	NS	NS
P vs. 3-week	***	NS	NS	NS	NS
Interval trend[u]	NS	NS	Q***	NS	NS

[z]Total number of actively growing terminal and lateral shoots quantified 60 days after initial treatment (DAIT).

[y]Average width = (widest width + width 90° to widest width) ÷ 2.

[x]Three applications of 200 ppm CYC made at a 1, 2, or 3 week interval.

[w]C = control plants; P = pruned plants.

[v]Nonsignificant (NS) or significant contrasts at α = 0.05 (*), 0.01 (**), or 0.001 (***).

[u]Nonsignificant (NS) or significant quadratic (Q) trend at α = 0.001 (***).

Table 3. CYC application interval and concentration effects on new shoot counts in 'Sky Pencil' holly from 120 to 150 days after initial treatment (DAIT) in 2007.

Concentration (ppm)	Shoot counts[z]	Application interval	Shoot counts
0	28	1	37*[y]
50	48	3	47*
100	44	6	55*
Significance[x]	L***		L***

[z]Total number of actively growing terminal and lateral shoots.

[y]Means followed by an asterisk were significantly different from the mean of the control, α = 0.05.

[x]Significant linear (L) trend at α = 0.001 (***).

and pruned controls were similar and less than the height of unpruned controls. Height at 120 DAIT changed quadratically in response to increasing application interval, and plants treated at 1 and 3 week application intervals were shorter than unpruned controls. Width was not affected by pruning or CYC application at 60 or 120 DAIT, and plants were not visibly injured by any treatment.

In 2007, there were no significant interactions between CYC concentration and application interval, except for plant width and quality rating at 180 DAIT. New shoot counts of 'Sky Pencil' holly were not affected by CYC application at 60 DAIT; however, at 120 to 150 DAIT new shoot counts increased linearly with increasing CYC concentration and increasing application interval (Table 3). When averaged across application interval, 'Sky Pencil' holly treated with 50 and 100 ppm CYC formed 71 and 57% more new shoots, respectively, than controls. When averaged across concentration, 'Sky Pencil' holly produced 32, 68, and 96% more new shoots than controls when CYC was applied at 1, 3 and 6 week intervals, respectively. Height of 'Sky Pencil' holly at 60 DAIT changed quadratically in response to increasing application interval, although differences were minor (Table 4). Plants in all CYC treatments were taller than controls at 60 DAIT. At 180 DAIT plant height decreased linearly with increasing application interval; however, only plants treated at the 6 week application interval were shorter than controls, indicating longer term height suppression with longer application intervals. At 60 DAIT, width of 'Sky Pencil' holly increased linearly with increasing application interval, and plants treated at a 3 or 6 week application interval were wider

Table 4. Cyclanilide application interval effects on height and width of 'Sky Pencil' holly and shoot counts of 'Snow White' Indian hawthorn in 2007[z].

	'Sky Pencil' holly			'Snow White' Indian hawthorn
Application interval (wk)	Height (cm) 60 DAIT	Height (cm) 120 DAIT	Width (cm)[y] 60 DAIT	Shoot counts[x] 60 DAIT
Control	27.9	58.5	6.1	18
1	22.4*[w]	54.8	6.7	39*
3	18.7*	51.6	7.9*	26*
6	21.0*	49.1*	7.3*	29*
Significance[v]	Q*	L*	L*	Q*

[z]Application interval × concentration interaction non- significant.

[y]Average width = (widest width + width 90° to widest width) ÷ 2.

[x]Total number of actively growing terminal and lateral shoots quantified 60 days after initial treatment (DAIT).

[w]Means followed by an asterisk were significantly different from that of the control (α ≤ 0.05).

[v]Significant linear (L) or quadratic (Q) trend at α = 0.05 (*).

Table 5. Cyclanilide application interval and concentration effects on width of 'Sky Pencil' holly and new shoot counts of 'Snow White' Indian hawthorn in 2007[z].

	'Sky Pencil' holly width[y] at 180 DAIT			'Snow White' Indian hawthorn shoot counts at 120 to 150 DAIT		
	Concentration (ppm)			Concentration (ppm)		
Application interval (wk)	0	50	100	0	50	100
Control	11.5	—	—	28	—	—
1	—	11.9	12.7*[x]	—	40*	33*[+]
3	—	11.1	13.8*[+w]	—	48*	45*
6	—	12.6*	14.0*[+]	—	55*	55*
Significance[v]		Q**	L*		L***	L***

[z]An application interval × concentration interaction affected both reported responses (α ≤ 0.05).

[y]Average width = (widest width + width 90° to widest width ÷ 2).

[x]Means followed by an asterisk are significantly different from that of the control (α ≤ 0.05).

[w]Means followed by a '+' sign are significantly different from the mean for 50 ppm treatment within the same application interval.

[v]Significant linear (L) or quadratic (Q) trend at α = 0.05 (*), 0.01 (**), or 0.001 (***).

Table 6. Cyclanilide application interval and concentration effects on quality rating[z] of 'Sky Pencil' holly and 'Snow White' Indian hawthorn at 180 days after initial treatment (DAIT) in 2007[y].

	'Sky Pencil' holly			'Snow White' Indian hawthorn		
	Concentration (ppm)			Concentration (ppm)		
Application interval (wk)	0	50	100	0	50	100
Control	2.0	—	—	2.2	—	—
1	—	3.4*[x]	3.5*	—	2.9*	3.4*
3	—	3.8*	3.8*	—	3.5*	3.7*
6	—	4.3*	4.8*	—	4.2*	4.2*
Significance[w]		L***	L***		L***	L***

[z]Rating of overall plant quality on a scale of 1–5 (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable).

[y]An application interval × concentration interaction affected all reported responses ($\alpha \leq 0.05$).

[x]Means followed by an asterisk are significantly different from that of the control ($\alpha \leq 0.05$).

[w]Significant linear (L) trend at $\alpha = 0.001$ (***).

than controls (Table 4). This increased width of CYC treated 'Sky Pencil' holly is particularly desirable during production because it could reduce the number of liners per pot necessary to produce a marketable plant. At 180 DAIT there was a significant interaction between CYC concentration and application interval for width; however, all CYC treated plants were wider than control, except when 50 ppm CYC was applied weekly or every 3 weeks (Table 5). Holland et al. (6) reported a similar increase in width of 'Sky Pencil' holly with 3 weekly applications of 100 to 300 ppm CYC. Plant quality rating increased linearly as application interval increased, supporting the use of longer application intervals. Plant quality was also higher for plants in all CYC treatments than for controls, due to an increase in plant density and width and a decrease in plant height (Table 6). There were no differences in quality ratings for plants receiving 50 or 100 ppm CYC at any application interval, suggesting an upper limit of 50 ppm when applied at any of the tested intervals. Holland et al. (6) reported a similarly higher quality of CYC treated plants due to a wider and more compact canopy. Results from this study indicate that CYC effectively promoted new shoot development in 'Sky Pencil' holly and is a viable alternative to pruning during production of this cultivar.

'Snow White' Indian hawthorn. Shoot counts of CYC treated Indian hawthorn at 60 DAIT in 2006 changed quadratically in response to increasing CYC application interval. Additionally, more new shoots formed on CYC treated plants than on pruned and unpruned controls (Table 7). CYC treated plants formed 162, 215, and 169% more new shoots than unpruned controls and 113, 156, and 119% more new shoots than pruned controls when treated at 1, 2, and 3

Table 7. Effects of cyclanilide application interval on growth of 'Snow White' Indian hawthorn in 2006.

	Shoot counts[z]	Plant height (cm)		Plant width[y] (cm)		Injury rating[x]	
Treatment	60 DAIT	60 DAIT	120 DAIT	60 DAIT	120 DAIT	60 DAIT	120 DAIT
Control	13	22.7	25.5	36.5	42.9	1.0	1.0
Pruned	16	16.8	22.9	27.4	37.3	2.3	1.2
1-week[w]	34	18.5	23.6	30.2	40.9	4.0	3.3
2-week	41	18.2	23.7	30.6	40.5	4.0	3.9
3-week	35	18.1	24.2	29.6	39.9	4.0	3.8
C vs. P[v]	NS[u]	***	NS	***	**	***	***
C vs. 1-week	***	**	NS	***	NS	***	***
C vs. 2-week	***	***	NS	**	NS	***	***
C vs. 3-week	***	***	NS	***	NS	***	***
P vs. 1-week	***	NS	NS	NS	NS	***	***
P vs. 2-week	***	NS	NS	NS	NS	***	***
P vs. 3-week	***	NS	NS	NS	NS	***	***
Interval trend[t]	Q*	NS	NS	NS	NS	NS	L*

[z]Total number of actively growing terminal and lateral shoots quantified 60 days after initial treatment (DAIT).

[y]Average width = (widest width + width 90° to widest width) ÷ 2.

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

[w]Three applications of 200 ppm CYC made at a 1, 2, or 3 week interval.

[v]C = control plants; P = pruned plants.

[u]Nonsignificant (NS) or significant contrasts at $\alpha = 0.01$ (**) or 0.001 (***).

[t]Nonsignificant or significant linear (L) or quadratic (Q) trend at $\alpha = 0.05$ (*).

week application intervals, respectively. At 60 DAIT height and width of pruned controls and CYC treated plants were similar, and less than those of unpruned controls, regardless of CYC application interval. These results concur with those of Holland et al. (5, 6), and indicate Indian hawthorn readily develops new shoots in response to CYC application. Height of CYC treated plants at 60 DAIT was reduced about 20%, while pruned plants were 26% shorter than controls. At 120 DAIT plant height was similar among all treatments, and width was only suppressed by pruning when compared to unpruned controls. Injury ratings of pruned controls and CYC treated plants were higher than those of unpruned controls at 60 and 120 DAIT. Injury symptoms on pruned controls included normal reddening of new growth. Injury was more severe on CYC treated plants at 60 DAIT and increased linearly with decreasing application interval at 120 DAIT. Symptoms included reddening, stunting, cupping and twisting of new growth. CYC treated plants at 120 DAIT were visibly lower in quality than pruned or unpruned controls, regardless of application interval due to foliar injury. Results from 2006 indicate that 200 ppm CYC applied at a 1, 2, or 3 week interval promoted new shoots in Indian hawthorn but because of foliar injury plants were unmarketable.

In 2007, at 60 DAIT, shoot counts of 'Snow White' Indian hawthorn changed quadratically in response to increasing CYC application interval. Plants treated weekly formed 50 and 34% more new shoots than plants treated at 3 and 6 week intervals, respectively (Table 4). Plants treated at 1, 3, and 6 week intervals formed 117, 44, and 61% more new shoots, respectively, than controls indicating an early benefit to a shorter application interval. In contrast, at 120 to 150 DAIT there was an interaction between application interval and concentration for shoot counts of 'Snow White' Indian hawthorn. Application of 50 or 100 ppm CYC resulted in a linear increase in shoot counts as application interval increased, and CYC treated plants formed more new shoots than controls (Table 5). Plants treated with 50 ppm CYC formed 43, 71 and 96% more new shoots than controls at 1, 3, and 6 week intervals, respectively. Plants treated with 100 ppm CYC formed 11, 61 and 96% more shoots when treated every 1, 3 and 6 weeks, respectively. The only effect of CYC concentration on shoot counts was the formation of 18% fewer shoots when 100 ppm was applied weekly compared to 50 ppm applied weekly. Treatment effects on plant height and width at 60 and 180 DAIT were not of horticultural significance (data not shown). Minor reddening and slight cupping or twisting of new shoots was evident about 10 DAIT on CYC treated plants and persisted until about 120 DAIT. Symptoms appeared to increase as application interval decreased. At 180 DAIT plant quality increased linearly as application interval increased (Table 6), supporting the use of longer application intervals. Plant quality was also higher for plants in all CYC treatments than for controls, reflecting a greater compactness and increased branching from CYC application (Table 6). As with 'Sky Pencil' holly, there were no differences in quality ratings for plants receiving 50 or 100 ppm CYC at any application interval, suggesting an upper limit of 50 ppm when applying CYC three times at any of the tested intervals.

Results of this study give further evidence that multiple applications of CYC promote longer term shoot production of specific woody shrubs than do single applications. In 2006, plants treated three times with 200 ppm CYC formed more new shoots than pruned and unpruned controls, usually regardless of application interval. Results from 2007 indicated that branching response was most persistent, injury was most transient, and end-of-season plant quality was highest when CYC was applied over a longer period than when the same number of applications was made more frequently. In 2007 CYC concentration had much less effect on growth of Indian hawthorn and holly than application interval and no effect in many cases. These results support previous findings in which three weekly or biweekly CYC applications increased shoot production and shoot production was minimally affected by increasing CYC concentration, which often only increased injury (6). 'Snow White' Indian hawthorn is more sensitive to CYC application than 'Sky Pencil' holly or 'Diana' sasanqua camellia but injury was less severe and more transient with longer application intervals and lower concentrations (50 or 100 ppm). Cyclanilide has the potential to substitute for mechanical pruning in the production of woody ornamental shrubs. However, optimal concentrations and application intervals must be determined to maximize efficacy while minimizing or avoiding injury.

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