Cyclanilide Promotes Shoot Production and Flowering of Coreopsis and Coneflower during Nursery Production[1]

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Abstract

Herbaceous perennials were screened for increased branching and flowering in response to foliar sprays of cyclanilide (CYC), a plant growth regulator with cytokinin-like activity. *Coreopsis verticillata* 'Crème Brulee' ('Crème Brulee' coreopsis) and *Rudbeckia fulgida* 'Goldsturm' ('Goldsturm' coneflower), the only two species that responded positively to CYC, were used in subsequent experiments evaluating CYC concentration, method of application, and stage of plant development at application. Foliar sprays of 25 to 100 ppm CYC promoted increased shoot development, flowering, and plant width of coreopsis and coneflower, although flowering was delayed. Applying foliar sprays to both species when they were vegetative resulted in similar or more new shoots and flowers than an application when plants exhibited early signs of approaching flowering or at both stages. Increases in shoot counts from the application of substrate drenches of CYC to coreopsis and coneflower generally were less than from foliar sprays, while flower counts either decreased with increasing CYC concentration (coreopsis) or were unaffected (coneflower).

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

Species used in this study: *Coreopsis verticillata* L. 'Crème Brulee' ('Crème Brulee' coreopsis), *Lantana ×hybrida* hort. 'New Gold' ('New Gold' lantana), *Pennisetum setaceum* (Forssk.) Chiov. 'Rubrum' (purple fountain grass), *Perovskia atriplicifolia* Benth. (Russian sage), and *Rudbeckia fulgida* Aiton 'Goldsturm' ('Goldsturm' coneflower).

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

Significance to the Nursery Industry

Herbaceous perennials are most marketable when well branched, compact, and in flower. Vegetative plants of many perennials are pruned multiple times during production to increase the number of potential flowering shoots and promote compactness and fullness prior to exposure to floral-inductive long days. A single foliar spray of 25 to 100 ppm cyclanilide (CYC) applied under nursery conditions while plants are vegetative can greatly enhance vegetative and reproductive shoot development, resulting in the formation of more flowers on 'Crème Brulee' coreopsis and 'Goldsturm' coneflower, but not 'New Gold' lantana, purple fountain grass, or Russian sage. Delaying CYC application until plants begin to exhibit a change from vegetative to reproductive growth is less effective than an earlier application, and applying CYC at both stages of growth provides no added benefit. Random plants treated with CYC did appear to wilt under high light and temperatures more readily than untreated plants, but the effect was temporary. Substrate drenches of CYC are less effective than foliar sprays in promoting new shoots and may reduce (coreopsis) or have no effect on flowering (coneflower). While CYC is not labeled for use on landscape plants, it does appear to have potential as a branching agent on certain herbaceous perennials.

Introduction

Herbaceous perennials were the fastest growing crop sector in floriculture between 1998 and 2009 with 2009 sales of $844 million, a 34.5% increase over this period (14). Produced by nurserymen, greenhouse growers, and perennial specialists, perennials are typically potted from plugs into larger containers in the fall, overwintered outdoors or in minimally heated greenhouses, and forced into flower for the spring market or allowed to flower during their natural flower period. Vegetative plants of many perennials are pruned multiple times to promote compactness and fullness and to increase the number of potential flowering shoots prior to exposure to floral-inductive conditions. However, pruning is labor intensive, and because of the tissue removed, each pruning will probably increase production time, as it has with woody shrubs (15).

Apical dominance, the suppression of lateral bud outgrowth by auxins produced in shoot apices, is broken when terminal shoots are removed (2, 11, 12). Exogenous application of cytokinins or plant growth regulators (PGRs) with cytokinin-like activity also can reduce apical dominance by counteracting auxin (6, 9, 10). Cyclanilide (CYC), a PGR currently marketed in combination with ethephon as the cotton defoliant Finish®, acts as an auxin transport inhibitor, temporarily interrupting apical dominance and allowing the outgrowth of latent lateral buds (3, 4, 13). CYC has promoted lateral shoot development in trees (3, 4), shrubs (1, 7, 8), and the herbaceous perennial, 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') during greenhouse production (5) when applied as foliar sprays (1, 3, 4, 5, 7, 8) or substrate drenches (5, 16). The objective of this study was to evaluate the effects of CYC on the growth and flowering of several herbaceous perennials when grown under outdoor nursery production conditions.

Materials and Methods

Experiment 1, 2007. On March 22, 2007, 72-cell liners of 'Crème Brulee' coreopsis (*Coreopsis verticillata* 'Crème Brulee'), purple fountain grass (*Pennisetum setaceum* 'Rubrum'), and 'New Gold' lantana (*Lantana ×hybrida* 'New

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Gold') from Greenleaf Nurseries (El Campo, TX) were repotted into 3.8 liter (#1) containers of a 7:1 pinebark:sand growth medium 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. Russian sage (*Perovskia atriplicifolia*) in 72-cell liners, also obtained from Greenleaf Nurseries, and 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm') in 10.2 cm (4 in) containers, obtained from the Ornamental Horticulture Research Center in Mobile, AL, were re-potted into 3.8 liter (#1) containers of the same growth medium on April 5, 2007. Plants were spaced outdoors in full sun at the Paterson Horticultural Complex, Auburn, AL, under twice-daily overhead irrigation totaling approximately 2.5 cm (1.0 in) per day. Plants were re-spaced as needed to prevent canopy overlap.

On May 24, 2007, when treatments were first applied, coreopsis and lantana had a few open flowers and coreopsis had numerous visible flower buds, while other species were growing vegetatively. Foliar sprays of 0, 5, 10, 20, 40, 50, or 75 ppm CYC were applied at 0.2 liter·m^{-2} (equivalent to 2 qt per 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 added at a rate of 0.2% to solutions containing CYC. Temperature and relative humidity at treatment were 30C (85F) and 51%, respectively. Plants were excluded from overhead irrigation for a minimum of 6 hours following treatment application before arranging in a completely randomized design within species using 10 single-plant replications. Because no visible response was evident on plants in any treatment 3 weeks later, a second application was made to all species on June, 14, 2007, when temperature and relative humidity were 31C (87F) and 52%, respectively. On June 29, 2007, 'Crème Brulee' coreopsis was pruned to 15.2 cm (6 in) above the substrate surface because plants were in full flower with little new vegetative growth, and shoots had elongated excessively, contributing to open canopies and containers frequently falling over.

Because there were no visible effects of CYC treatment on growth or flowering of purple fountain grass, 'New Gold' lantana, or Russian sage, no data were collected on these species. For coreopsis, all open flowers were counted at 4 and 8 weeks after first treatment (WAT), and all shoots (terminal and lateral) ≥ 2.5 cm (1.0 in) in length were counted at 6 WAT. For coneflower, plant height and widths (mean of widest and perpendicular widths), terminal and lateral shoot counts, and open flower and flower bud counts were quantified at 6 WAT. Data were analyzed as a completely randomized design using PROC MIXED in SAS version 9.2 (SAS Institute, Cary, NC). The ANOVA normality assumption was tested using the tests for normality statistics in PROC UNIVARIATE. Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were significant. However, no significant non-normality was found for any of the response variables. The ANOVA homogeneous variance assumption was tested in PROC MIXED using the GROUP option on the REPEATED statement and corrected when the null model likelihood ratio test was significant. Single degree of freedom orthogonal contrasts were used to test linear and quadratic response trends over the cyclanilide concentrations. All tests were considered significant at $\alpha = 0.05$.

Experiment 2, 2008. Experiments conducted in 2008 used methodology similar to 2007, unless otherwise noted, and were limited to coreopsis and coneflower, species that responded positively to CYC treatments in 2007. Based on the short period between treatment application and flowering of coreopsis and a lack of any visible response prior to pruning in 2007, foliar sprays of several CYC concentrations were applied at two stages of development in the second experiment. 'Crème Brulee' coreopsis and 'Goldsturm' coneflower in 72-cell plug flats were re-potted into 0.9 liter (1 qt) containers on November 3, 2007, and over-wintered outdoors before repotting into 3.8 liter (#1) containers on April 4, 2008. Experiment 2 was a 3 [developmental stage (DS 1, DS 2, DS 1 + 2)] × 4 (CYC concentration) factorial plus a CYC control with treatments arranged in a completely randomized design and replicated with eight single-plant replications. Foliar sprays of 25, 50, 75, or 100 ppm CYC were applied to coreopsis on April 18, 2008, when the dry bulb temperature and relative humidity were 24C (75F) and 54%, respectively. Coreopsis treated at DS 1 or DS 1 + 2 were growing vegetatively and were 13 to 18 cm (5.1 to 7.1 in) tall. On April 25, 2008, foliar spray of 25, 50, 75, or 100 ppm CYC were applied to coreopsis at DS 2 and DS 1+2 when the dry bulb temperature and relative humidity were 26C (78F) and 52%, respectively. Small, immature flower buds were visible on a few random shoots of coreopsis at DS 2. Coneflower in DS 1 and DS 1+2 treatments received a foliar spray of 25, 50, 75, or 100 ppm CYC on May 2, 2008, when the dry bulb temperature and relative humidity were 25C (77F) and 47%. At this time coneflower stems had not begun to elongate and were 7 to 12 cm (2.8 to 4.7 in) tall. On June 9, 2008, coneflower in DS 2 and DS 1+2 treatments received a foliar application of the same CYC concentrations. Stems of coneflower treated at DS 2 were elongating into flowering stalks although no flower buds were visible. Initial plant height, days to first flower and full flower (peak floral display), and shoot number, open flower number, plant height, and growth index {GI = [(height + widest width + width 90° to widest width) ÷ 3]} at full flower were recorded for coreopsis. For coneflower, initial plant height, days to first flower and full flower (five fully opened flowers), and plant height, widths, basal shoot number, flower bud number, and flower diameter of the five fully opened flowers at full flower were recorded. Data were analyzed as a completely randomized design with stage of development and cyclanilide concentration in a partial factorial treatment arrangement using PROC MIXED in SAS version 9.2. Normality and homogeneity of variance assumptions were checked as in experiment 1. Initial plant height was tested as a covariate and included in the model as a linear effect if the Akaike information criteria (AIC) value was reduced when compared to the model AIC value without the covariate. Single degree of freedom orthogonal contrasts were used to test linear and quadratic response trends over the cyclanilide concentrations, including the control, and paired contrasts were used to compare means among the stages of development at each cyclanilide concentration. Paired contrasts were also used to compare the control to each of the stages of development. All tests were considered significant at $\alpha = 0.05$.

Experiment 3, 2008. This experiment was conducted to evaluate the effect of CYC substrate drenches when applied at two developmental stages on growth and flowering of

'Crème Brulee' coreopsis and 'Goldsturm' coneflower. This experiment was conducted simultaneously to experiment 2 using identical methodology unless noted. Drench applications of 25, 50 and 75 ppm CYC were applied at DS 1 or DS 2, but not both. Drenches of 250 ml (0.3 qt), applied on the same dates as foliar sprays were applied in the second experiment, were poured over the crown of each plant to moist substrate, resulting in ~10% leachate. Treatments in this 2 × 3 factorial experiment were completely randomized within species and replicated with eight single-plant replications. Data collection and analyses were identical to those in the second experiment.

Results and Discussion

Experiment 1, 2007. CYC concentration had no effect on flower number of 'Crème Brulee' coreopsis at 4 WAT or shoot number at 6 WAT (data not shown), possibly because open flowers and flower buds were visible when CYC was first applied or because plants were under photo-inductive long-day photoperiods when or soon after treatments were applied, contributing to flowering at the expense of vegetative shoot growth. Pruning of coreopsis to 15.2 cm (6 in) in height at 5 WAT removed all flowers and most flower buds and promoted rapid shoot growth that terminated in flowers. At 8 WAT, CYC treated coreopsis were visibly fuller than control plants, and flower counts increased linearly, 75 to 330%, with increasing CYC concentration (Table 1). Similarly, flower counts were increased when CYC was applied to 'Moonbeam' coreopsis during greenhouse production (5). Random plants treated with CYC appeared to wilt under high light and temperatures more readily than controls, but the effect was not evident at 8 WAT. This wilting effect contrasts with the twisted and horizontal growing shoots that persisted until full flower following CYC application to 'Moonbeam' coreopsis during greenhouse production (5).

At 6 WAT, shoot counts of 'Goldsturm' coneflower increased linearly, up to 47%, as CYC concentration increased. Flower and flower bud counts changed quadratically with the most, 103% more than on control plants, forming on plants treated with 20 ppm CYC. Most shoots terminated in flower buds as evidenced by similar numbers of shoots and flowers or flower buds at 6 WAT. Plant height of treated plants decreased linearly, up to 6% as CYC concentration increased, while plant width changed quadratically, ranging from 19 to 32% greater than in controls for plants receiving 40 and 5 ppm CYC, respectively. Increased width and a slight height reduction resulted in plants that appeared less top-heavy and more proportional to the container. Previous research has reported growth in plant height and width following CYC application to be suppressed, promoted, or not affected, depending upon species and CYC treatment, although suppression was more common than promotion (1, 7, 8, 16). All CYC treated plants developed slightly puckered leaves that persisted for about two weeks after treatment and that minimally detracted from plant appearance. A few CYC-treated plants also appeared to wilt more readily than control plants during hot days despite being adequately irrigated. This effect lasted for about 6 weeks and did not appear to be related to CYC concentration.

In summary, CYC promoted increased shoot development, flowering, or both in 'Crème Brulee' coreopsis and 'Goldsturm' coneflower, but not in purple fountain grass, 'New Gold' lantana, or Russian sage. 'Crème Brulee' coreopsis under nursery conditions has a relatively short period of marketability due to its rapid shoot elongation, heavy flowering, and subsequent lodging. In this experiment a few open flowers and numerous flower buds were present on 'Crème Brulee' coreopsis when CYC was first applied that very likely reduced any effect of CYC on new shoot formation or flowering. Flower counts in coreopsis increased following pruning, suggesting that CYC application at an earlier stage of plant development may be more effective. CYC promoted new shoot development and flowering of 'Goldsturm' coneflower, while slightly suppressing plant height and increasing plant width. Based on these results, subsequent experiments included only 'Crème Brulee' coreopsis and 'Goldsturm' coneflower and focused on CYC concentration and method of application (spray or drench), and plant stage of development when CYC was applied.

Experiment 2, 2008. Similar trends occurred in days to first and full flower of 'Crème Brulee' coreopsis, even though CYC concentration and DS interacted for only days

Table 1. Effects of CYC foliar sprays on 'Créme Brulee' coreopsis and 'Goldsturm' coneflower, 2007.

	8 WAT[z]	6 WAT			
CYC (ppm)	Flower counts[y]	Height (cm)	Width[x] (cm)	Shoot counts[w]	Flower counts[y]
	Coreopsis	Coneflower			
0	20	52.8	46.9	95	69
5	35	54.0	61.7	110	119
10	51	51.8	56.1	109	118
20	59	51.7	60.8	123	140
40	75	51.3	55.8	118	93
50	66	48.3	56.4	145	118
75	86	49.7	56.6	140	109
Sign.[v]	L***	L*	Q**	L***	Q**

[z]Weeks after first treatment (coreopsis) or treatment (coneflower).

[y]Open flowers (coreopsis) or open flowers and flowers buds (coneflower).

[x]Mean of the widest width + width perpendicular.

[w]Total number of terminal and lateral shoots.

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

Table 2. **Interactive effects of plant stage of development and CYC foliar spray concentration on 'Créme Brulee' coreopsis and 'Goldsturm' coneflower, 2008.**

	CYC conc. (ppm)					
Stage[z]	0	25	50	75	100	Sign.[y]
	Coreopsis					
	Days to flower					
Control	24					
1		28b[x]	28c	30c	29c	Q*
2		25b	35b	36b	33b	Q**
1 + 2		37a	39a	41a	40a	Q***
	Shoot number[w]					
Control	278					
1		792a	1470a	1294a	899a	Q***
2		879a	862b	683b	870a	Q***
1 + 2		733b	745c	636c	645b	Q***
	Flower number[v]					
Control	142					
1		739a	1075a	1132a	832a	Q***
2		835a	811b	680b	799a	Q***
1 + 2		838a	701b	639b	568b	Q***
	Coneflower					
	Basal shoot number					
Control	10					
1		11a	11b	16a	16b	L***
2		10a	10b	9b	10c	NS
1 + 2		10a	14a	17a	24a	L***
	Flower bud number					
Control	98					
1		145a	131b	195a	197a	L***
2		122b	114c	117c	128b	L***
1 + 2		120b	182a	188b	196a	L***
	Flower diameter[u]					
Control	7					
1		7a	7a	6a	7a	NS
2		7a	7a	7a	7a	NS
1 + 2		7a	6a	5b	5b	L***
	Average width (cm)[t]					
Control	49.9					
1		65.2a	62.1a	74.9a	67.2a	Q***
2		60.6a	51.6b	60.0b	61.5a	L**
1 + 2		56.4b	65.6a	62.3b	56.1b	Q***

[z]Stage of shoot development when CYC was applied; 1: vegetative and 13 to 18 cm tall (coreopsis) or 7 to 12 cm tall (coneflower); 2: small, immature flower buds visible on a few random shoots (coreopsis) or shoots elongating but no visible flower buds (coneflower).

[y]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) response, $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

[x]Means within columns and attributes followed by different letters were significantly different based on single degree of freedom contrasts, $\alpha = 0.05$.

[w]Total number of terminal and lateral shoots at full flower.

[v]Number of blooms with fully reflexed ray flowers.

[u]Mean diameter of the five open blooms at full flower. [t](Widest width + width 90° to widest width) ÷ 2 at full flower.

[t](Widest width + width 90° to widest width) ÷ 2 at full flower.

to first flower. Days to first flower changed quadratically with increasing CYC concentration, regardless of the DS when plants were treated, with the greatest delay occurring between the control and the lowest CYC concentration, except when plants were treated at DS 2 (Table 2). Flowering was delayed the least when plants were treated at DS 1, followed by DS 2, and the most when treated at both stages. Compared to the control, delays to full flower due to CYC concentration ranged from 9 to 12 days and 8, 11, and 13 days when CYC was applied at DS 1, DS 2, and DS 1 + 2, respectively (Table 3). These delays in flowering concur with those reported in crapemyrtle (*Lagerstroemia* 'Muskogee') (1), but contrast with the lack of effect on time to flower when CYC was applied to 'Moonbeam' coreopsis (5). As with days to first flower, CYC concentration and DS interacted for shoot and flower counts at full flower, both attributes changed quadratically with increasing CYC concentration, and the greatest change was between the control and the lowest CYC concentration (Table 2). Relative to those of the control, shoot counts increased 185 to 429%, 146 to 216%, and 129 to 168% when coreopsis was treated at DS 1, DS 2, and DS 1 + 2, respectively, while flower counts increased 420 to 697%, 379 to 488%, and 300 to 490% when treated at the same stages. These increases in shoot counts and flowering following CYC application are consistent with those reported for 'Moonbeam' coreopsis during greenhouse production (5). In general, fewer shoots and flowers formed when CYC was applied at a later developmental stage or at both stages. Plant height of coreopsis at full flower was not affected by CYC, while GI of plants treated at DS 1 or DS 2 was greater than that of plants treated at both stages or of controls, indicating an increase in width of plants treated once with CYC (Table 3). As in the previous experiment, random plants treated with CYC appeared to wilt under high light and temperatures more readily than controls.

Days to first and full flower of 'Goldsturm' coneflower were affected by DS, but not CYC concentration (data not shown), with the least delay in flowering when CYC was applied at DS 2 (2 to 3 days) and similar delays when applied at DS 1 or DS 1 + 2 (6 to 8 days) (Table 3). Basal shoot counts increased linearly, by up to 60 and 140%, when plants were treated with CYC at DS 1 and DS 1 + 2, respectively, but were unaffected by CYC application at DS 2 (Table 2). Flower bud counts increased linearly by 48 to 101%, 24 to 31%, and 22 to 100% with increasing CYC concentration when applied at DS 1, DS 2, and DS 1 + 2, respectively, and were higher when applied at all CYC concentrations, except 25 ppm, in plants treated at DS 1 or DS 1 +2. CYC foliar sprays likewise promoted increased reproductive shoot and flower bud development in 'Moonbeam' coreopsis (5). Flower diameter was reduced by up to 29% when CYC was applied at DS 1 + 2, but not affected by a single CYC application. Plant height decreased linearly, up to 10%, with increasing CYC concentration, and only plants treated at DS 1 + 2 were shorter than the control (Table 3). In contrast, plants generally were wider when treated with CYC than control plants, and plants treated at DS 1 were as wide as or wider than plants treated later or twice (Table 2). As noted with coreopsis, random plants of coneflower tended to wilt more readily during periods of high light and temperature than did control plants.

In this experiment, foliar sprays of 25 to 100 ppm CYC promoted increased shoot development, flowering, and

Table 3. Significant main effects of plant stage of development and CYC foliar spray concentration on 'Créme Brulee' coreopsis and 'Goldsturm' coneflower, 2008.

	Coreopsis			Coneflower		
Stage[z]	Days to flower	GI[y] at full flower		Days to first flower	Days to full flower	Height (cm) at full flower
1	36c*[x]	51.6b*		70b*	75a*	62a
2	39b*	54.8a*		66c*	71b	60a
1 + 2	41a*	48.3c		71a*	75a*	52b*
Control	28	45.1		63	69	60

	CYC conc. (ppm)					
Attribute	0	25	50	75	100	Sign.[w]
Coreopsis						
Days to full flower	28	37	39	40	39	Q***
Coneflower						
Height (cm) in full flower	60	62	58	58	54	L**

[z]Stage of shoot development when CYC was applied; 1: vegetative and 13 to 18 cm tall (coreopsis) or 7 to 12 cm tall (coneflower); 2: small, immature flower buds visible on a few random shoots (coreopsis) or shoots elongating but no visible flower buds (coneflower).

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

[x]Means within columns and attributes followed by different letters were significantly different based on single degree of freedom contrasts, $\alpha = 0.05$. Means followed by an asterisk (*) were significantly different from that of the control based on contrasts, $\alpha = 0.05$.

[w]Significant (Sign.) linear (L) or quadratic (Q) response at $\alpha = 0.01$ (**) or 0.001 (***).

plant width of 'Crème Brulee' coreopsis and 'Goldsturm' coneflower, although flowering was delayed. Treating both species when vegetative (DS 1) resulted in similar or more new shoots and flowers than when plants exhibited early signs of approaching flowering (DS 2): small flower buds (coreopsis) and bolting (rudbeckia), and applying CYC at both times offered no added benefit to a single early foliar spray. In most cases, the most positive responses of 'Crème Brulee' coreopsis and 'Goldsturm' coneflower occurred over the range of CYC concentrations, with relatively minor differences among concentrations.

Experiment 3, 2008. Time to first flower of 'Crème Brulee' coreopsis increased by up to 2 days when plants were drenched with increasing CYC concentrations, and by 3 and 1 day when they were drenched at DS 1 and DS 2, respectively (Table 4). Delays to full flower were greater than those to first flower when plants were drenched at DS 1, 4 to 11 days, but

Table 4. Significant main effects of plant stage of development and CYC drench concentration on 'Créme Brulee' coreopsis and 'Goldsturm' coneflower, 2008.

	Coreopsis		Coneflower
Stage[z]	Days to first flower	GI[y] at full flower	Flower diameter[x]
1	25a*[w]	51.0a	5.9a*
2	23b*	46.8b	5.8b*
Control	22	49.3	5.4

	Coreopsis				
	CYC conc. (ppm)				
Attribute	0	25	50	75	Sign.[v]
Days to full flower	22	23	24	24	L***
Flower number at full flower	228	158	157	139	L*
GI at full flower	49.3	48.8	49.7	46.6	L*

[z]Stage of shoot development when CYC was applied; 1: vegetative and 13 to 18 cm tall (coreopsis) or 7 to 12 cm tall (coneflower); 2: small, immature flower buds visible on a few random shoots (coreopsis) or shoots elongating but no visible flower buds (coneflower).

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

[x]Mean diameter of the five open flowers at full flower.

[w]Means within columns and attributes followed by different letters were significantly different based on single degree of freedom contrasts, $\alpha = 0.05$. Means followed by an asterisk (*) were significantly different from that of the control based on contrasts, $\alpha = 0.05$.

[v]Significant (Sign.) linear (L) response, $\alpha = 0.05$ (*) or 0.001 (***).

Table 5. **Interactive effects of plant stage of development and CYC drench concentration on 'Créme Brulee' coreopsis and 'Goldsturm' coneflower, 2008.**

Stage[z]	CYC conc. (ppm) 0	25	50	75	Sign.[y]
	Coreopsis				
	Days to full flower				
Control	24				
1		28a[x]	35a	35a	L***
2		27a	26b	26b	NS
	Shoot number at full flower				
Control	340				
1		266b	509a	446a	L***
2		421a	422a	434a	L**
	Coneflower				
	Days to first flower				
Control	65				
1		66a	65a	64b	NS
2		60b	65a	72a	Q*
	Days to full flower				
Control	71				
1		74a	72a	71b	NS
2		66b	72a	77a	Q*
	Basal shoot number at full flower				
Control	8				
1		12a	10a	8a	NS
2		7b	9a	12a	Q*
	Width (cm)[w]				
Control	48.8				
1		63.9a	56.8a	58.1a	Q*
2		43.5b	51.1a	48.8a	NS

[z]Stage of shoot development when CYC was applied; 1: vegetative and 13 to 18 cm tall (coreopsis) or 7 to 12 cm tall (coneflower); 2: small, immature flower buds visible on a few random shoots (coreopsis) or shoots elongating but no visible flower buds (coneflower).

[y]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) response, α = 0.05 (*), 0.01 (**), or 0.001 (***) level.

[x]Means within a column and attribute followed by different letters are significantly different based on single degree of freedom contrasts, μ = 0.05. Means followed by an asterisk (*) are significantly different from that of the control based on contrasts, α = 0.05.

[w](Widest width + width 90° to widest width) ÷ 2 at full flower.

unaffected by CYC concentration when drenched at DS 2 (Table 5). CYC substrate drenches also delayed time to flower of 'Moonbeam' coreopsis when applied during greenhouse production (5). Shoot counts at full flower increased linearly by up to 50 and 28% with increasing CYC concentration when plants were treated at DS 1 and DS 2, respectively (Table 5), but flower counts decreased 31 to 39%, regardless of stage when treated (Table 4). This reduction in flowering contrasts with the increased flowering from foliar sprays of CYC recorded in the two previous experiments. Plant height at full flower was not affected by CYC concentration (data not shown), while GI was minimally reduced by increasing concentration (Table 4). In contrast to foliar sprays in the first two experiments, plants drenched with CYC did not exhibit wilting before control plants during periods of high light intensity and temperature.

Days to first flower of 'Goldsturm' coneflower drenched with increasing CYC concentrations changed quadratically when treated at DS 2, with plants receiving 25 ppm CYC flowering 5 days before controls and those treated with 75 ppm CYC flowering 7 days after controls; plants treated at DS 1 were unaffected by CYC concentration (Table 5). Days to full flower followed similar trends. Basal shoot counts at full flower changed quadratically with increasing CYC concentration, with a 50% increase from the application of 75 ppm CYC at DS 2, but no effect when applied at DS 1. In contrast to the previous two experiments with foliar sprays, CYC drenches had no effect on flower bud counts (data not shown), whereas flower diameter of plants treated with CYC at both developmental stages was greater than that of controls (Table 4). Plants treated with CYC at DS 1 were 16 to 31% wider than controls, but unaffected by CYC concentration when treated at DS 2 (Table 5). Drenches did not promote earlier wilting of coneflower as sprays had, possibly because drenches were less effective overall.

In this two-year study evaluating CYC effects on herbaceous perennials, foliar sprays of CYC were not effective on all species, which agrees with previous research with CYC (7, 8). Of the species that responded positively to CYC, coreopsis and coneflower, foliar sprays of 25 to 100 ppm increased shoot counts, flowering, and plant width, all responses that should enhance marketability. However, flowering was delayed and random plants of both species appeared to wilt more readily during periods of high light intensity and temperature than control plants, even though the substrate was still moist. Positive responses were greater when CYC was applied to vegetative plants (DS 1) than to plants with immature flower buds (coreopsis) or shoots that had begun to elongate (coneflower); also, there was no further benefit from applying CYC at both developmental stages. Results of applying substrate drenches of CYC to coreopsis and coneflower were mixed. Delays in flowering were minimal except when applied at DS 1 to coreopsis, increases in shoot counts were less than with foliar sprays, and flower counts either decreased with increasing CYC concentration (coreopsis) or were unaffected (coneflower). While CYC is not registered for use on herbaceous perennials, it does appear to have potential as a branching agent for use on coreopsis and coneflower when applied as a foliar spray to vegetative plants during nursery production.

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