Benzyladenine and Cyclanilide Promote Shoot Development and Flowering of 'Moonbeam' Coreopsis[1]

M.E. Farris[2], G.J. Keever[3], J.R. Kessler[3], and J.W. Olive[4]
Department of Horticulture
Auburn University, AL 36849

Abstract

Effects of cyclanilide (CYC) and benzyladenine (BA) applied as foliar sprays or substrate drenches on the growth and flowering of 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') during greenhouse production were determined. A foliar spray or substrate drench of 250 to 2000 ppm BA promoted increased numbers of vegetative shoots, reproductive shoots, and flower buds that increased with concentration. With BA concentrations of 250 or 500 ppm, flowering was delayed by 7 days or less and any foliar chlorosis was transient. Flowering delays of up to 19 days and persistent foliar chlorosis occurred in plants treated with 1000 or 2000 ppm BA. CYC applied at 25 to 100 ppm promoted fewer vegetative and reproductive shoots and flower buds than did BA; however, compared to control plants, plants developed more flower buds with no flowering delay, except when applied as a 100 ppm drench. Plants treated with CYC foliar sprays or substrate drenches developed twisted and horizontal growing shoots that persisted until full flower and detracted from the plants' appearance.

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

Species used in this study: *Coreopsis verticillata* L. 'Moonbeam'.

Chemical used in this study: benzyladenine (BA) [N-(phenylmethyl)-1*H*-purine-6-amine]; cyclanilide [1-(2, 4-dichlorophenylamino-carbonyl)-cyclopropane carboxylic acid].

Significance to the Nursery Industry

Vegetative plants of 'Moonbeam' coreopsis are typically pruned multiple times 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 or basal drench of 250 to 2000 ppm benzyladenine (BA) can greatly enhance vegetative and reproductive shoot development of 'Moonbeam' coreopsis resulting in the formation of more flower buds. However, because of temporary foliar chlorosis and a significant delay in flowering from 1000 to 2000 ppm BA, BA should not be applied at concentrations above 500 ppm. Cyclanilide (CYC) at 25 to 100 ppm also stimulated 'Moonbeam' coreopsis to produce more reproductive shoots and flower buds than controls, but fewer than BA. Of the concentrations tested, 25 ppm CYC resulted in the most flower buds without a delay in flowering, although all concentrations resulted in some twisting of shoots and a more horizontal growth habit, aesthetically unacceptable. Both BA and CYC have the potential to enhance flowering of 'Moonbeam' coreopsis and provide more shoots for vegetative propagation, although morphological responses to CYC are a limitation.

Introduction

Coreopsis verticillata 'Moonbeam' ('Moonbeam' coreopsis), the 1992 Perennial Plants of the Year (14), bears pastel yellow flowers on terminal and axillary shoots from late spring through summer. To produce saleable plants of 'Moonbeam' coreopsis for the peak spring market requires propagation from cuttings or division, though tip cuttings are more widely used (12). Tip cuttings are commonly harvested from stock plants from fall through spring or any time flowers are not present. Following rooting and repotting, vegetative plants are typically pruned multiple times to increase the number of potential flowering shoots and promote compactness and fullness prior to exposure to floral-inductive long days.

Cytokinins are naturally occurring plant hormones and synthetic growth regulators that function in overcoming apical dominance and promoting lateral bud outgrowth (11). Exogenous foliar or drench applications of the cytokinin, benzyladenine (BA), have promoted new shoot development in numerous herbaceous and woody landscape plants (4, 5, 9, 10, 13, 15). A foliar spray of 250 to 1000 ppm BA increased the number of lateral branches of *Peperomia obtusifolia* (L.) Dietr. and suppressed plant height due to reduced internode length (5). Foliar sprays of BA also stimulated offset formation in *Hosta* Tratt., which was cultivar dependent (4). Foliar sprays of BA stimulated lateral shoot formation and reduced internode length in pot carnation (*Dianthus caryophyllus* L.) without affecting days to flowering, flower number, or flower diameter (15). More recently, foliar sprays of the bioregulator cyclanilide (CYC) promoted lateral shoot development in apple (*Malus* ×*domestica* Borkh.) and cherry (*Prunus avium* L.) trees (2, 3) and several woody landscape species (1, 6, 7). In unpublished studies at Auburn University substrate drenches of CYC promoted new shoot development of container-grown nursery stock at lower concentrations than foliar sprays. The objective of this study was to determine the effects of CYC and BA applied as foliar sprays and substrate drenches on growth and flowering of 'Moonbeam' coreopsis during greenhouse production.

Materials and Methods

Experiment 1. On November 8, 2007, non-flowering, terminal shoots, 2.5 to 3.8 cm (1.0 to 1.5 in) long, of 'Moonbeam' coreopsis were stuck without any rooting hormone in

[1]Received for publication March 3, 2009; in revised form April 27, 2009.
[2]Graduate Assistant.
[3]Professors. keevegj@auburn.edu
[4]Superintendent, Ornamental Horticulture Research Center, Mobile, AL 36608.

288-cell flats containing Fafard Germination Mix (Conrad Fafard, Anderson, SC). The shoots rooted under intermittent mist propagation set to 5 seconds on every 5 minutes from 8:00 am to 5:00 pm in a shaded (72% light reduction), glass covered greenhouse with a heating set point of 23.3C (74F) and a ventilation set point of 26.7C (80F) under natural photoperiods. Rooted cuttings were transplanted to 10.2 cm (4 in) square × 11.4 cm (4.5 in) deep plastic pots containing Fafard 3B potting medium (Conrad Fafard) on November 25, 2007. All plants were spaced pot to pot in an un-shaded 8 mm (0.3 in) twin wall, polycarbonate covered greenhouse with a heating set point of 18.3C (65F) and ventilation set point of 25.6C (78F) with natural photoperiods. Liquid fertilization was begun when roots were visible at the bottom and sides of the container medium, and was applied 2 or 3 times weekly at a concentration of 150 ppm nitrogen using a 20N–4.4P–16.6K (Pro Sol 20–10–20, Frit Industries, Inc., Ozark, AL). Plants were watered or fertilized by hand when the medium appeared dry, but before plants wilted. Plants were re-spaced as they grew.

On January 15, 2008, 136 'Moonbeam' coreopsis, 1 to 1.5 cm (0.4 to 0.6 in) in height, were selected for uniformity. Plants chosen had compressed, dormant shoots and roots visible at the bottom and sides of the container medium. The following treatments were applied on the same date: an untreated control, 25, 50, 75, or 100 ppm CYC, or 250, 500, 1000, or 2000 ppm BA as a foliar spray or medium drench (17 treatments). Spray treatments included a non-ionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), at 0.2% and were applied at 0.2 liters·m^{-2} (equivalent to 2 qt·100 ft^{-2}) using a CO^2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi). Drench treatments were applied in a volume of 59.2 ml (2 oz)·pot^{-1} over the crown of each plant. Dry bulb temperature and relative humidity at time of application ranged from 21 to 23C (70 to 73F) and 50 to 56%, respectively. Because 'Moonbeam' coreopsis is a long day plant for shoot elongation and flowering with no chilling requirements (11), night interrupted lighting (NIL) from 10:00 pm to 2:00 am was provided beginning on January 20, 2008. This experiment was a 2 (method of application) × 4 (concentration) factorial within each plant growth regulator (PGR), plus a control (17 treatments). The 17 treatments were replicated with 8 single plants each, and plants were arranged in a completely randomized design.

Data collection included: counts of basal shoots ≥ 1 cm (0.4 in) in length at 2 and 3 weeks after treatment (WAT); basal shoot length (mean of three longest basal shoots) at 3 WAT; foliar chlorosis rating at 4 WAT using a 1–5 scale (1 = 0%, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of foliage exhibiting chlorosis); number of days to first flower (when one flower was fully open); height and width [width = (widest width + width 90° to widest width) / 2] at first flower; number of days to full flower (when five flowers were fully open); counts of basal vegetative shoots ≥ 1 cm, counts of basal reproductive shoots ≥ 1 cm, and counts of flower buds at full flower. Data were analyzed using PROC GENMOD in SAS version 9.1.3 (SAS Institute, Cary, NC). The ANOVA normality assumption for counted data was checked using 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 at $\alpha = 0.05$. Counted data were analyzed using the normal, the Poisson or the negative binomial probability distribution depending on which distribution minimized the Pearson Chi-Square test for goodness of fit, and injury ratings were analyzed using the multinomial probability distribution. Medians were reported for injury ratings. Single degree of freedom orthogonal contrasts were used to test linear and quadratic treatment trends over PGR concentration, and paired comparison contrasts were used to compare application methods within a concentration, $\alpha = 0.05$.

Experiment 2. Experiment 1 was repeated using the same methodology unless otherwise stated. On February 5, 2008, 136 actively growing 'Moonbeam' coreopsis plants were blocked by plant height and treatments applied. Plants used in the second experiment were from the same group propagated in November 2007 and averaged six to eight elongated shoots per plant with an average length of the longest shoot per plant of 9.7 cm and a range of 9.0 to 10.5 cm across treatment averages. Dry bulb temperature and relative humidity at the time of treatment application ranged from 24 to 26C (75–78F) and 75 to 82%, respectively. Data collection and analysis were identical except that no data were taken at 2 WAT, and lateral shoots (shoots branching off basal shoots ≥ 1 cm in length) were also counted at 3 WAT.

Results and Discussion

Experiment 1. At 2 WAT, there was an interaction between concentration and method of application for basal shoot number of plants treated with CYC or BA (Table 1). Basal shoot number decreased linearly by up to 80% with spray application and by up to 88% with drench application as the concentration of CYC increased. 'Moonbeam' coreopsis treated with a 50 ppm spray of CYC developed 200% more basal shoots than those treated with a 50 ppm drench (1.5 vs. 0.5). Plants treated with a spray of 250, 500, 1000, and 2000 ppm BA formed 74, 378, 169, and 600% more basal shoots, respectively, than those treated with a drench of the same concentrations. At 3 WAT, basal shoot number of 'Moonbeam' coreopsis treated with BA was 22% greater than that of plants treated with CYC (Table 2). Plants receiving a spray application of BA formed 43% more basal shoots that were 60% longer than those receiving a drench application of the PGR. Similarly, plants treated with a spray of CYC formed 46% more basal shoots than those treated with a drench; however, a drench application of CYC promoted basal shoots that were 21% longer than those treated with a spray application. As concentration of CYC increased, basal shoot number decreased linearly by 22%, and basal shoot length decreased by 49%. Basal shoot numbers of 'Moonbeam' coreopsis responded quadratically to increasing concentrations of BA, with the most shoots formed on plants treated with 500 ppm. Basal shoot length of plants treated with BA decreased linearly by 57% as concentration increased. These results suggest an early suppression in basal shoot outgrowth following the foliar and drench application of BA and CYC at the tested concentrations.

At 4 WAT plants treated with either BA or CYC were visibly lighter green than controls, and there was an interaction between BA or CYC concentration and method of application for the injury rating (Table 1). Injury rating increased linearly with increasing PGR concentration when CYC was applied as a spray and when BA was applied as a spray or as a drench.

Table 1. Interactive effects of BA or CYC concentration and application method on the growth and flowering of 'Moonbeam' coreopsis, expt. 1.

		2 WAT[z]		4 WAT				At first flower[y]				At full flower[x]	
		Basal shoot no.		Injury rating[w]		Days to first flower		Height (cm)		Days to full flower		Vegetative shoot no.	
PGR	Concn. (ppm)	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench
CYC	0	4.0	4.0	1.0[v]	1.0	—[u]	—	38.9	38.9	63	63	—	—
	25	2.3	2.8	2.0	2.0	—	—	39.9***	33.5	64	64	—	—
	50	1.5*[t]	0.5	2.5	2.0	—	—	37.4***	28.4	64	65	—	—
	75	0.8	1.6	2.5	3.0	—	—	35.8***	29.1	67	65	—	—
	100	1.0	0.6	3.5***	2.0	—	—	35.6***	20.9	66	69	—	—
Significance[s]		L***	L***	L***	Q**	—	—	L*	L***	NS	L**	—	—
BA	0	4.0	4.0	1.0	1.0	59	59	38.9	38.9	63	63	5.5	5.5
	250	4.0*	2.3	1.5	1.0	60	63	38.9	39.1	63	66	6.8*	10.8
	500	4.3***	0.9	2.0	2.5	63	64	38.1	37.5	67	70	14.0	15.6
	1000	4.3***	1.6	4.0***	2.0	65	65	36.8	38.0	70	71	18.9***	12.4
	2000	2.8***	0.4	4.5***	4.0	67***	75	38.4**	32.5	74***	82	16.3	19.8
Significance		NS	L***	L***	L***	L***	L***	NS	L***	L***	L***	L***	L***
CYC		1.4***		2.4		59.7***		32.6***		65***		5.1***	
BA		2.6		2.6NS		65.1		37.4		70		14.3	

[z]Weeks after treatment on January 15, 2008.

[y]When petals (ray flowers) on the first opened flower (inflorescence) were fully reflexed.

[x]When petals (ray flowers) on the first 5 open flowers (inflorescences) were fully reflexed.

[w]The percentage of the total leaf area exhibiting foliar chlorosis (1 = 0%, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100%).

[v]Values are medians.

[u]Dashes indicate no interaction between application method and concentration; results shown in table 2.

[t]Nonsignificant (NS or no *) or a significant difference between application methods within a concentration or between PGRs at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

[s]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $\alpha=0.05$ (*), 0.01 (**) or 0.001 (***); control included in trend analysis.

Injury rating changed quadratically with increasing CYC concentration when applied as a drench, with the highest rating of 3.0 given to plants treated with 75 ppm. This chlorosis dissipated over time and was no longer evident on plants in any treatment at first flower, except those treated with the highest concentrations of BA or CYC sprays or drenches. At 5 WAT, plants treated with BA appeared fuller and more compact than controls and plants treated with CYC, while shoots of plants treated with CYC were twisted and had assumed a more horizontal growth habit, which appeared to increase with concentration and detracted from plant appearance. Adverse symptoms on CYC-treated plants persisted until the experiment was terminated at full flower.

'Moonbeam' coreopsis treated with BA flowered an average of 5 days later than plants treated with CYC (Table 1). Days to first flower was not affected by CYC concentration (Table 2). However, there was an interaction between application method and concentration for days to first flower of plants treated with BA and for height at first flower of plants treated with CYC or BA (Table 1). Days to first flower of plants treated with a BA spray increased linearly, by 8 days, while those treated with a drench increased linearly, by 16 days, as PGR concentration increased. Plants receiving a drench of 2000 ppm BA reached first flower 8 days later than plants receiving a spray of 2000 ppm. Height at first flower of sprayed 'Moonbeam' coreopsis decreased linearly, by 9%, as the concentration of CYC increased. Height of plants that were drenched with CYC also decreased linearly, by 46%. Plants that received sprays of 25, 50, 75, and 100 ppm CYC were 19, 32, 23, and 70% taller than those receiving a drench of the same concentration, indicating a greater suppression in shoots elongation from drench-applied CYC than when CYC was applied as a foliar spray. At first flower, plants treated with CYC were 5% wider than those treated with BA (Table 2). There was no difference in width of plants treated with a BA spray or drench, but plants treated with a CYC drench were 12% narrower than those treated with a CYC spray, indicating a greater activity of drench applications.

There was an interactive effect of application method and concentration on days to full flower of plants treated with BA or CYC and on vegetative shoot number of plants treated with BA (Table 1). 'Moonbeam' coreopsis treated with BA reached full flower 5 days later than plants treated with CYC. There was no difference in days to full flower of plants treated with a CYC spray; however, days to full flower of plants treated with a CYC drench increased linearly, by up to 6 days, as concentration increased. For those plants receiving a spray application of BA, time to full flower increased linearly, by up to 11 days, while those receiving a drench increased by up to 19 days, as concentration increased. Similar to days to first flower, plants treated with a drench of 2000 ppm BA reached full flower 8 days later than those treated with a 2000 ppm spray. Vegetative shoot numbers were 180% greater for plants treated with BA than for those treated with CYC (Table 1). Vegetative shoot numbers increased linearly, up to 244%, for plants treated with a BA spray and by up to 260% for plants treated with a BA drench as concentration increased. Plants receiving a drench of 250 and 1000 ppm BA had 59 and 52% more vegetative shoots, respectively, than those receiving a spray of the same concentrations.

Table 2. Effects of the application method and concentration of CYC and BA on growth and flowering of 'Moonbeam' coreopsis, expt. 1.[z]

PGR	Concn. (ppm)	3 WAT[y] Basal shoot no.	3 WAT[y] Basal shoot length (cm)[v]	Days to first flower	At first flower[x] Average width (cm)[u]	At full flower[w] Flower bud no.	At full flower[w] Vegetative shoot no.	At full flower[w] Reproductive shoot no.
CYC	0	6.3	7.9	59	51.7	92.1	5.5	15.3
	25	6.4	6.2	59	47.4	111.6	4.4	15.9
	50	5.6	4.6	59	45.3	112.1	5.6	17.6
	75	4.8	4.7	59	42.6	121.1	5.1	17.0
	100	4.9	4.0	62	41.6	99.3	5.4	15.1
Significance[t]		L*	L***	NS	L***	Q**	NS	NS
BA	0	6.3	7.9	—[s]	51.7	92.1	—	15.3
	250	6.8	6.3	—	44.4	108.2	—	27.1
	500	7.7	4.9	—	41.1	137.8	—	38.0
	1000	6.6	4.5	—	43.1	147.2	—	41.1
	2000	5.1	3.4	—	40.4	150.3	—	47.0
Significance		Q*	L***	—	L***	L***	—	L***
CYC	Spray	6.4***[r]	4.4**	60NS	46.8***	108.7NS	5.8NS	16.4NS
	Drench	4.4	5.3	59	41.7	113.3	4.4	16.4
BA	Spray	7.7***	5.9***	—	42.9NS	136.3NS	—	39.8NS
	Drench	5.4	3.7	—	41.6	135.5	—	36.9
CYC		5.4**	4.9NS	60***	44.3*	111.0***	5.1***	16.4***
BA		6.6	4.8	65	42.3	135.9	14.3	38.4

[z]There were no application method × PGR interactions for these data.

[y]Weeks after treatment on January 15, 2008.

[x]When petals (ray flowers) on the first opened flower (inflorescence) were fully reflexed.

[w]When petals (ray flowers) on the first 5 open flowers (inflorescences) were fully reflexed.

[v]Mean of the three longest basal shoots.

[u]Average width = (widest width + width 90°) / 2.

[t]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at α = 0.05 (*), 0.01 (**), or 0.001 (***); control included in trend analysis.

[s]Dashes indicate an interaction between application method and concentration; results shown in table 1.

[r]Nonsignificant (NS) or a significant difference between application methods or PGRs at α = 0.05 (*), 0.01 (**), or 0.001 (***).

There was no difference between CYC application methods or among concentrations for vegetative shoot numbers at full flower. Flower bud number was 22% greater in plants treated with BA than in those treated with CYC, while application method had no effect (Table 2). Flower bud numbers changed quadratically in response to increasing CYC concentrations, with the highest counts on plants treated with 75 ppm. Flower bud numbers on plants treated with BA increased linearly, by up to 63%, with increasing concentration. Also at full flower, plants treated with BA had formed 134% more reproductive shoots than those treated with CYC, while application method had no effect on reproductive shoot numbers. Reproductive shoot numbers of plants treated with BA increased linearly, by up to 207%, with increasing concentration, while CYC concentration had no effect.

Results from experiment 1 indicate that foliar sprays or substrate drenches of BA or CYC delayed shoot outgrowth in the weeks immediately following treatment, that foliage of treated plants developed chlorosis that dissipated before first flower, except when plants received the highest concentrations of BA or CYC, and that BA, and to a lesser extent CYC, delayed time to flower of 'Moonbeam' coreopsis. Conversely, a foliar spray or substrate drench of 250 to 2000 ppm BA promoted increased numbers of vegetative and reproductive shoots and more flower buds. Plants treated with BA were shorter and narrower with a visibly greater shoot density than control plants. Flowering delays of up to 19 days and persistent foliar chlorosis in plants treated with 1000 or 2000 ppm BA suggest that BA should not be applied at concentrations above 500 ppm. With BA concentrations of 500 ppm or less, flowering was delayed by 7 days or less and foliar chlorosis was transient, while vegetative and reproductive shoot counts were greater than those of controls. Compared to BA, CYC promoted fewer vegetative and reproductive shoots and flower buds; however, compared to control plants, plants treated with 25 to 100 ppm CYC developed more blooms with no flowering delay, except for a delay in time to full flower of up to 6 days when CYC was applied as a 100 ppm drench. However, the twisted and horizontal growing shoots evident at 5 WAT in CYC-treated plants persisted until full flower and detracted from the plants' appearance.

Experiment 2. There was no difference between CYC and BA in their effect on basal shoot number or length at 3 WAT; nor were basal shoot number and length affected by BA and CYC application methods, respectively (Table 3). However, plants treated with a BA spray had shoots that were 21% longer than those treated with a drench, and plants receiving a spray application of CYC formed 41% more basal shoots than those drenched. CYC concentration had no effect on basal shoot number or length, while BA concentration did not affect basal shoot number. As in experiment 1, basal shoot length decreased linearly, by up to 65%, as BA concentration increased. Plants treated with BA developed 11% more lateral shoots than plants treated with CYC, while those treated with a BA spray developed 551% more lateral shoots than plants receiving a drench. Thus, BA sprays stimulated lateral shoot development at 3 WAT (29.3 shoots), relative to that of controls (16.7 shoots), while BA drenches suppressed lateral shoot development (4.5 shoots). These differences may relate to the generally greater activity of drench applications. Lateral shoot numbers responded quadratically to increasing concentrations of BA, with the most shoots on plants treated with 250 or 500 ppm BA. CYC concentration did not affect lateral shoot number.

As in experiment 1, plants treated with BA or CYC developed foliar chlorosis by 4 WAT. Injury ratings taken at that time increased linearly with increasing concentration when BA was applied as a spray or drench, but were not affected by CYC concentration when applied as a spray or as a drench (Table 4). In general, CYC applied as a spray or drench resulted in less leaf chlorosis than BA applied as a spray or drench, and there appeared to be less foliar chlorosis overall than in the first experiment. Although not as pronounced as in experiment 1, shoots of plants treated with CYC were again twisted and more horizontal growing by 5 WAT, which detracted from plant appearance. These symptoms appeared to increase with CYC concentration and persisted until the experiment was terminated at full flower.

'Moonbeam' coreopsis treated with BA reached first flower about 2 days later than plants treated with CYC (Table 3). BA application method did not affect days to first flower. However, there was a linear increase in time to first flower of up to 6 days in response to increasing concentrations of BA. Plants receiving a spray application of CYC reached first flower 6 days later than those receiving a drench and 5 days later than controls. There were application method and concentration interactions for height and average width at first flower of plants treated with CYC or BA (Table 4). Similar to experiment 1, plants treated with BA were 8% taller than plants treated with CYC. Heights of plants treated with a BA or CYC spray or drench decreased linearly, with the greatest drench concentrations of both PGRs resulting in the shortest plants. Plants treated with CYC were 18% wider than those treated with BA, and similar to experiment 1, width of plants treated with CYC or BA decreased linearly with increasing concentrations, regardless of application method.

In experiment 2, 'Moonbeam' coreopsis reached full flower about 23 days earlier than plants in experiment 1, probably because shoots had elongated and plants were actively growing when treated (Tables 1 and 3). Similar to days to first flower, plants treated with CYC reached full flower about 2 days before those treated with BA, and CYC sprays delayed time to full flower 6 days, compared to CYC

Table 3. Effects of CYC and BA application method and concentration on growth and flowering of 'Moonbeam' coreopsis, expt. 2.[z]

PGR	Concn. (ppm)	3 WAT[y] Basal shoot no.	3 WAT Basal shoot length (cm)[w]	3 WAT Lateral shoot no.	Days to first flower[v]	Days to full flower	At full flower[x] Flower bud no.	At full flower Vegetative shoot no.	At full flower Reproductive shoot no.
CYC	0	10.2	27.2	16.7	36	42	—[u]	3.1	11.3
	25	11.2	21.8	16.4	37	42	—	4.5	15.1
	50	11.6	19.0	16.3	38	43	—	4.7	16.4
	75	9.7	19.7	17.1	38	44	—	3.6	16.1
	100	11.3	16.7	10.9	39	44	—	6.0	20.8
Significance[t]		NS	NS	NS	NS	NS	—	NS	L*
BA	0	10.2	37.2	16.7	36	42	102.0	—	—
	250	9.9	26.6	18.9	36	42	102.8	—	—
	500	10.1	18.7	18.9	39	45	124.8	—	—
	1000	10.4	15.7	17.0	41	47	141.0	—	—
	2000	9.5	13.0	12.7	42	52	131.6	—	—
Significance		NS	L**	Q*	L***	L***	Q**	—	—
CYC	Spray	12.8**[s]	16.4NS	16.4NS	41***	46***	—	5.3NS	20.8***
	Drench	9.1	22.1	13.9	35	41	—	4.1	13.4
BA	Spray	10.5NS	18.9*	29.3*	40NS	45NS	124.8NS	—	—
	Drench	9.4	15.6	4.5	39	47	125.3	—	—
CYC		11.0NS	19.3NS	15.2*	38*	44***	145.2***	4.7***	17.1***
BA		10.0	17.3	16.9	40	46	125.1	14.1	35.9

[z]There were no application method × PGR interactions for these data.
[y]Weeks after treatment on February 5, 2008.
[x]When petals (ray flowers) on the first 5 open flowers (inflorescences) were fully reflexed.
[w]Mean of the three longest basal shoots.
[v]When petals (ray flowers) on the first opened flower (inflorescence) were fully reflexed.
[u]Dashes indicate an interaction of application method and concentration; results shown in table 4.
[t]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at α = 0.05 (*), 0.01 (**), or 0.001 (***); control included in trend analysis.
[s]Nonsignificant (NS) or significant difference between application methods or PGRs at α = 0.05 (*), 0.01 (**), or 0.001 (***).

Table 4. Interactive effects of CYC or BA concentration and application method on the growth and flowering of 'Moonbeam' coreopsis, expt. 2.

				At first flower[z]				At full flower[y]					
		Injury rating[x]		Height (cm)		Average width[w] (cm)		Flower bud no.		Vegetative shoot no.		Reproductive shoot no.	
PGR	Concn. (ppm)	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench	Spray	Drench
CYC	0	1.0[v]	1.0	42.1	42.1	51.9	51.9	102.0	102.0	—[u]	—	—	—
	25	1.0	1.0	36.0	36.3	47.2*[t]	52.2	154.0***	103.4	—	—	—	—
	50	1.0	1.0	33.0	32.1	43.8**	51.6	165.6***	117.4	—	—	—	—
	75	1.0	1.0	32.9	30.5	42.7***	51.4	165.5	154.9	—	—	—	—
	100	1.0	1.0	32.1***	23.1	43.9	42.1	175.3***	117.8	—	—	—	—
Significance[s]		NS	NS	L***	L***	L***	L***	L***	L**	—	—	—	—
BA	0	1.0	1.0	42.1	42.1	51.9	51.9	—	—	3.1	3.1	11.6	11.6
	250	2.0	1.0	37.2	35.9	48.6	43.7	—	—	6.4	8.1	18.4	22.1
	500	2.0	2.0	38.5	37.0	44.7*	39.7	—	—	7.5	11.2	21.4***	38.1
	1000	3.5**	2.0	35.7	33.9	40.0	36.4	—	—	13.9**	20.7	36.8***	54.1
	2000	4.0**	3.0	34.4***	24.0	38.4***	25.3	—	—	14.8***	29.4	35.8***	60.6
Significance		L***	L***	L***	L***	L***	L***	—	—	L***	L***	L***	L***
CYC		1.1		32.0***		46.9***		145.2***		4.7***		17.1***	
BA		2.4		34.6		39.6		125.1		14.1		35.9	

[z]When petals (ray flowers) on the first opened flower (inflorescence) were fully reflexed.

[y]When petals (ray flowers) on the first 5 open flowers (inflorescences) were fully reflexed.

[x]The percentage of the total leaf area exhibiting foliar chlorosis (1 = 0%, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100%).

[w]Average width = (widest width + width 90°) / 2.

[v]Values are medians.

[u]Dashes indicate no interaction between application method and concentration; results shown in table 3.

[t]Nonsignificant (no *) or a significant difference between application methods within a concentration or between PGRs at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

[s]Nonsignificant (NS) or significant linear (L) trends at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***); control included in trend analysis.

drenches (Table 3). Days to full flower of plants treated with BA increased linearly by up to 10 days with increasing concentration, while CYC concentration had no effect on days to full flower. In contrast to experiment 1, 'Moonbeam' coreopsis treated with CYC produced 16% more flower buds than plants treated with BA, although numbers were similar for BA-treated plants in the two experiments. Flower bud number increased linearly, 51 to 72% and 1 to 16%, for plants that received a CYC spray and drench, respectively (Table 4). Plants receiving spray applications of 25, 50, and 100 ppm CYC formed 49, 41, and 49% more flower buds, respectively, than those treated with drenches of the same concentration. Flower bud number changed quadratically as BA concentration increased (Table 3), with the most flower buds developing in response to 1000 ppm BA and no difference between application methods. Similar to experiment 1, 'Moonbeam' coreopsis treated with BA formed 200% more vegetative shoots and 110% more reproductive shoots than plants treated with CYC. Vegetative shoot numbers of plants that received spray and drench applications of BA increased linearly by up to 377 and 848%, respectively, in response to increasing BA concentrations (Table 4). Plants that received a drench of 1000 and 2000 ppm BA produced 49 and 99% more vegetative shoots, respectively, than those that received a spray of the same concentration. Similar to vegetative shoot numbers, reproductive shoot numbers of plants that received spray and drench applications of BA increased linearly by up to 209 and 422%, respectively, in response to increasing concentration. Plants treated with a drench of 500, 1000, and 2000 ppm BA produced 78, 47, and 69% more reproductive shoots, respectively, than plants treated with a spray of the same concentrations. Vegetative shoot number of plants treated with CYC was not affected by application method or concentration (Table 3). Reproductive shoot number increased linearly, by up to 84% in response to increasing CYC concentration, and plants treated with a CYC spray produced 55% more reproductive shoots than those treated with a drench.

Results of experiment 2 were generally consistent with those of experiment 1 even though BA and CYC applications were made to plants at different stages of development: dormant plants with compressed shoots versus actively growing plants with elongated shoots. In both experiments 250 to 2000 ppm BA promoted greater vegetative and reproductive shoot numbers than 25 to 100 ppm CYC when applied as a foliar spray or substrate drench. However, when BA was applied at concentrations above 500 ppm, flowering was delayed longer and foliar chlorosis was more persistent. In other studies bronzing and cupping of new foliage occurred when BA was applied to Olivia™ Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl. 'Conia') (13); however, BA promoted increased shoot production in carnation with no flowering delay or injury (15). Compared to control plants, CYC promoted more reproductive shoots and flower buds with no delay in flowering. However, shoot increases were not as high as those promoted by BA, and plants developed persistent twisted shoots and a more horizontal growth habit, which detracted from plant appearance. A similar change in growth habit was reported following CYC application to *Ternstroemia gymnanthera* (Wight & Arn.) Bedd., in which new shoot proliferations formed distal rosettes on long branches resulting in an unattractive drooping appearance (8). Multiple applications of CYC have also caused bronzing, stunting, and cupping of foliage in Indian hawthorn (6).

Results of our evaluation of CYC and BA on the shoot development and flowering of *Coreopsis verticillata* 'Moonbeam' indicate that a foliar spray or substrate drench of 250 to 500 ppm BA applied to dormant or actively growing vegetative plants effectively promoted vegetative and reproductive shoot formation and flower bud production with minimal delay in flowering and only transient foliar chlorosis. Greater concentrations of BA resulted in more persistent foliar chlorosis and delays in flowering that were considered unacceptable for commercial production. Plants treated with BA, regardless of application method, were more uniform and compact than control plants and those treated with CYC, in both experiments. Compared to control plants, CYC promoted more reproductive shoots and flower buds with no delay in flowering. However, shoot increases were not as high as those promoted by BA, and an unattractive more horizontal growth habit detracted from plant appearance. In conclusion, BA appears to have more potential in the production of 'Moonbeam' coreopsis than CYC, but should not be used above 500 ppm to avoid persistent foliar chlorosis and a significant flowering delay.

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