Growth Retardant Use on Herbaceous Perennials Grown Under Night-Interrupted Lighting Outdoors in the Southern United States[1]

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Abstract

A study was conducted in 2002 and 2003 to determine if growth retardants could be used to suppress stem elongation of 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') and 'Goldsturm' coneflower (*Rudbeckia fulgida* Aiton 'Goldsturm') when grown outdoors under nursery conditions in the southern United States without negating the benefits of earlier flowering from night-interrupted lighting (NIL). Night-interrupted lighting accelerated flowering of both cultivars without adversely affecting flower and flower bud counts or plant quality. However, plants grown under NIL generally were taller than plants grown under natural photoperiod (NP). When several PGRs [Cutless, B-Nine, B-Nine/Cycocel, Bonzi (2002 only), and Sumagic (2003 only)] were applied to plants under NIL, results varied with PGR type and concentration and year. Height of 'Moonbeam' coreopsis was effectively suppressed by 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel in both years of the study and with 40 or 60 ppm Sumagic in the one year it was tested. Higher concentrations of Cutless and B-Nine suppressed height growth in 1 of 2 years, while Bonzi was ineffective. None of the PGR types or concentrations suppressed height growth of 'Goldsturm' coneflower to the level of the NP control in 2002. However, in 2003 when an additional application of Cutless and B-Nine were made, and Bonzi was replaced with Sumagic, applications of Cutless, B-Nine, B-Nine/Cycocel, and Sumagic all resulted in heights similar to or less than that of plants under NP with minimal effects on time to flower or flower and flower bud counts.

Index words: flower induction, long-day plant, growth regulator, container production, nursery production.

Species used in this study: 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm'); 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam').

Growth retardants used in this study: B-Nine (daminozide) [butanedioic acid mono (2,2-dimethylhydrazide)]; Bonzi (paclobutrazol) [(R*,R*)-β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol]; Cutless (flurprimidol) [α-(1-methylethyl)-α-[4-(trifluoromethoxy)phenyl]-5- pyrimidinemethanol]; Cycocel (chlormequat) [(2-chloroethyl) trimethylammonium chloride]; and Sumagic (uniconazole-P) [(E)(S)-1(4-chlorophenyl)4,4-dimethyl-2(1,2,4-triazol-1-yl) pent-1-ene-3-ol].

Significance to the Nursery Industry

Long-day herbaceous perennials like 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam') and 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm') can be forced to flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod (2, 8, 12, 24, 25). Growers in the southern United States have a similar opportunity for early forcing without adversely affecting flower and flower bud counts by exposing plants to night-interrupted lighting (NIL) outdoors from 10 p.m. to 2 a.m. However, NIL using incandescent lamps can promote excessive shoot elongation. Height of 'Moonbeam' coreopsis was effectively suppressed by 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel in both years it was tested and with 40 or 60 ppm Sumagic in the one year it was tested. Higher concentrations of Cutless and B-Nine suppressed height growth in 1 of 2 years, while Bonzi was ineffective in the 1 year it was tested. None of the PGR types or concentrations suppressed height growth of the later-blooming 'Goldsturm' coneflower to the level of the natural photoperiod (NP) control in the first year of the study. However, in the second year, applications of Cutless, B-Nine, B-Nine/Cycocel, and Sumagic all resulted in heights similar to or less than that of NP controls. The greater height control in the second year probably was related to one or more of the following: the later potting date of plugs in the second experiment, to the additional application of Cutless and B-Nine, to substituting Sumagic for Bonzi, or to temperature differences during the two experiments. While year-to-year differences in height control occurred, results indicate that of the PGRs tested, multiple applications of 5000 or 7500 ppm B-Nine/1500 ppm Cycocel mixes or single applications of 40 or 60 ppm Sumagic were most effective in suppressing height growth of 'Moonbeam' coreopsis and 'Goldsturm' coneflower when timed to periods of rapid shoot elongation.

Introduction

Flowering is controlled by internal and external factors, including exposure to low temperatures (vernalization) and photoperiod (4, 20, 22). Vernalization promotes flowering at subsequent higher temperatures (21), and even when vernalization is not required for flowering, many herbaceous perennials benefit from cold exposure by earlier or improved flowering (2, 3, 8). Photoperiod is a reliable environmental signal for flower induction that has been artificially manipulated by greenhouse growers to keep plants vegetative or induce flowering. Under natural short days (SDs), night-interrupted lighting (NIL) from 10:00 p.m. to 2:00 a.m. generally is recommended to induce flowering of long-day plants (LDPs) (2, 3, 8), including the qualitative LDPs, 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam') (9) and 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm') (25). In quantitative LDPs, long days are not required to induce flowering,

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but are beneficial in either hastening the rate of flowering or increasing the number of flowers (2, 3).

While the above cited photoperiod research was conducted in greenhouses or in growth chambers under climate controlled conditions, similar responses were reported in LDPs grown outdoors under nursery conditions in the southeastern United States where environment control was lacking (13, 14). Coastal states in the South, primarily in USDA hardiness zone 8, experience cool nights and mild days in late winter that provide ideal conditions for growing many herbaceous perennials. When NIL was initiated outdoors at different times in late winter and continued until visible floral development, flowering of 'Goldsturm' coneflower was accelerated by 26 to 46 days in 1999 and by 51 to 75 days in 2000 when compared to plants grown under a natural photoperiod (NP) (13). Night-interrupted lighting accelerated time to flower and increased flower counts of 'Moonbeam' coreopsis by 7 to 36 days and 20 to 244%, respectively (14). However, 'Goldsturm' coneflower grown under NIL was 18 to 23% (1999) and 48 to 52% (2000) taller than plants under natural photoperiods (NP) at anthesis and plant quality rating was lower in both years. Similarly, 'Moonbeam' coreopsis under NIL was up to 155% taller than plants under NP.

Plant growth retardants (PGRs), including B-Nine (daminozide), B-Nine/Cycocel (chlormequat chloride) mixes, Bonzi (paclobutrazol), and Sumagic (uniconazole), are frequently used to control the growth of horticultural crops during greenhouse production (6, 23). However, efficacy was reduced when PGRs were applied outdoors under nursery conditions as compared to in a greenhouse (7). Cutless (flurprimidol), a turf PGR that was recently labeled for herbaceous and woody ornamentals during production, has also been effective in suppressing growth of herbaceous perennials (5, 7), including 'Moonbeam' coreopsis under greenhouse conditions (15). Yuan et al. (25) reported that 'Goldsturm' coneflower tended to be too tall when grown in 10.2 cm (4 in) or 15.2 cm (6 in) pots in a greenhouse, and that A-Rest, B-Nine, Bonzi, and Cycocel only slightly reduced plant height, although concentrations applied were not given. The objective of this study was to determine if PGRs could be used to control stem elongation of 'Moonbeam' coreopsis and 'Goldsturm' coneflower grown outdoors under nursery conditions in the southern U.S. without negating the benefits of earlier flowering from NIL.

Materials and Methods

'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam')' and 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm') were transplanted on November 2, 2001, from 72-cell flats (Green Leaf Perennials, Lancaster, PA) into 2.8 liter (#1 trade) pots containing milled pine bark:peat (3:1, by vol) substrate. The growth medium was amended per m^3 (yd^3) with 8.3 kg (14 lb) 17N-3P-10K (Osmocote 17-7-12, The Scotts Company, Marysville, OH), 3.6 kg (6 lb) dolomitic limestone, 1.2 kg (2 lb) gypsum, and 0.9 kg (1.5 lb) Micromax (The Scotts Company). Coreopsis plants were 2 to 4 cm (0.8 to 1.6 in) tall when transplanted, and coneflower were 3 to 5 cm (1.2 to 2.0 in) tall. Plants were grown pot-to-pot outdoors in full sun through the winter under NPs at the Ornamental Horticulture Research Center, Mobile, AL (USDA cold hardiness zone 8b; 30.7° north latitude, 88.2° west longitude), and were watered as needed from overhead impact sprinklers. Pots were respaced as plants grew so that plant canopies did not overlap. Plants were covered with white polyethylene when temperatures approaching –6.7C (20F) were predicted. As the season progressed and plants grew, the minimum temperature for protection was increased.

A night-interrupted lighting block was established outdoors in the nursery area to provide a minimum of 10 foot-candles of light from 10:00 p.m. to 2:00 a.m. Sixty watt incandescent lamps were spaced 1.3 m (4 ft) on center within rows and 1.5 m (5 ft) between rows. Lamps were placed 1.2 m (4 ft) above ground level and 1.1 m (3.5 ft) or less above plants. Photosynthetically active radiation at plant height, as measured with a LI-COR LI-6400 steady-state porometer (LI-COR Biosciences, Lincoln, NE), averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NIL area. Space limitations prevented the replication of the lighting set-up. On February 1, 2002, 130 plants of each cultivar were moved under NIL, and 10 plants of each cultivar remained as unlighted controls. A black plastic curtain separated plants receiving NIL and unlighted control plants to a height of 1.8 m (6 ft) to prevent light leakage. The curtain was pulled in place at 4:00 p.m. daily and removed at 8:00 a.m. daily beginning February 1, and continued until all plants had the first open flower.

On March 22, 2002, when 'Moonbeam' coreopsis under NIL and NP averaged 11.8 cm (4.6 in) and 2.9 cm (1.1 in) tall, respectively; 'Goldsturm' coneflower under NIL and NP averaged 19.9 cm (7.8 in) and 3.2 cm (1.3 in) tall, respectively; and all plants under NIL had begun to elongate vigorously, the following PGR treatments were applied without the addition of a surfactant: Cutless at 50, 100, and 150 ppm; B-Nine at 2500, 5000, and 7500 ppm; B-Nine/Cycocel combinations at 2500/1500, 5000/1500, and 7500/1500 ppm; and Bonzi at 50, 100, and 150 ppm. Treatments also included untreated control plants under NIL. PGR treatments were applied at 0.2 liters$\cdot m^{-2}$ (equivalent to 2 qt$\cdot$100 ft^{-2}) using a CO_2 sprayer with a flat fan spray nozzle (XR TeeJet 8004, Bellspray, Inc., Opelousas, LA) at 414 kPa (60 psi). Temperature and relative humidity (RH) at treatment were 10C (50F) and 74%, respectively. Plants were not exposed to irrigation or rainfall for at least 12 hours after treatment. B-Nine and B-Nine/Cycocel treatments were reapplied on April 2, 2002, when temperature and RH were 20C (68F) and 55%, respectively. Plant cultivars were treated as separate experiments, and all treatments included 10 single plants.

The date of the first fully-opened flower (inflorescence) was recorded when ray flowers were fully reflexed. At this time, flower and flower bud counts, plant height from the substrate surface to the uppermost plant part, and quality rating were determined. Rather than actual flower and flower bud counts, flowering of 'Moonbeam' coreopsis was rated on the following scale: 1 = 0, 2 = 1 to 50, 3 = 51 to 100, 4 = 101 to 150, and 5 > 150 flowers and flower buds per plant. Quality rating varied slightly between the two cultivars but in general was as follows: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower count as compared to '4'; 4 = medium green foliage, less stem elongation and a larger plant than those rated '3', adequate flowers and flower buds; and 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings. The quality rating scale, while subjective, was the consensus of four individuals and represented an effort to quantify and rank in one rating several factors that impacted overall plant

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quality: compactness, fullness, foliar color and flowering. The ratio of plant height to pot height, as well as fullness, was considered in rating stem elongation. All ratings were assigned by one person.

The experiment was repeated the following winter using similar methodology except as noted below. Transplants of the two cultivars were repotted on December 13, 2002. The Bonzi treatments were ineffective in suppressing plant height in the first experiment and were replaced with Sumagic applied at 20, 40, and 60 ppm. Because 'Moonbeam' coreopsis flowered much sooner than 'Goldsturm' coneflower and because differences in the effectiveness of the PGRs in controlling plant height of the two cultivars in the first experiment were found, treatments were reapplied every 7 days up to three times if the uppermost internode was visibly longer than the two internodes immediately below it; reapplication was based on each cultivar's response to individual PGRs. 'Moonbeam' coreopsis was treated with all PGRs on March 17, 2003 [19C (67F) and 95% RH] and with B-Nine and B-Nine/Cycocel mixes on March 24, 2003 [24C (75F) and 55% RH]. 'Goldsturm' rudbeckia was treated with all PGRs on March 17, 2003; with Cutless, B-Nine, and B-Nine/Cycocel mixes on March 24, 2003; and with B-Nine on March 31, 2003 [12C (54F) and 78% RH]. At first treatment 'Moonbeam' coreopsis under NIL and NP averaged 18.3 and 3.2 cm (7.2 and 1.3 in) tall, respectively; 'Goldsturm' coneflower under NIL and NP averaged 14.2 and 2.7 cm (5.6 and 1.1 in) tall, respectively; and all plants under NIL were growing vigorously.

In both experiments, an analysis of variance was performed on data using PROC MIXED in SAS version 9.1.3 (SAS Institute, Cary, NC). The normality assumption for ANOVA was tested using the normality statistics from PROC UNIVARIATE (18). Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were significant ($\alpha = 0.05$). Plant height was analyzed using PROC MIXED; days to visible bud, days to flower, and flower counts were analyzed with PROC GENMOD using either the Poisson or negative binomial probability distribution depending on which distribution minimized the Pearson Chi-Square test for goodness of fit. Where necessary, heterogeneous variance was corrected in PROC MIXED using the group option on the repeated statement when the null model likelihood ratio test was significant ($\alpha = 0.05$). Flower number scale for 'Moonbeam' coreopsis and quality rating for both species were analyzed with PROC GENMOD using the multinomial probability distribution and a cumulative logit link; values presented in tables are medians for each treatment. Single degree of freedom polynomial contrasts were used to test linear and quadratic trends and paired comparison contrasts were used to compare treatments to the natural photoperiod ($\alpha = 0.05$).

Table 1. Average monthly temperatures and departures from normal for Mobile, AL, from February through June 2002 and 2003.

	Temperature [C (F)][z]			
Month	2002	Departure[y]	2003	Departure
February	10.2 (50.3)	–1.7 (–3.0)	12.1 (53.7)	0.2 (0.4)
March	15.1 (59.1)	–0.5 (–0.9)	16.7 (62.0)	1.1 (1.9)
April	21.0 (69.8)	2.4 (4.3)	19.4 (67.9)	1.1 (2.0)
May	23.2 (73.7)	0.2 (0.4)	25.2 (77.3)	2.2 (4.0)
June	26.4 (79.6)	0.3 (0.5)	26.7 (80.0)	0.6 (1.0)

[z]Temperatures measured 1.5 m (5 ft) above the ground.

[y]Departure from normal (30-year average); weather data provided by the NOAA, National Climatic Data Center.

Results and Discussion

Average monthly temperatures in Mobile, AL, ranged from 1.7C (3.0F) below normal in February 2002 to 2.4C (4.3F) above normal in April 2002, and from 0.2C (0.4F) above normal in February 2003 to 2.2C (4.0F) above normal in May 2003 (Table 1). Over the February to June duration of the study, average temperatures were 0.1 and 1.0C (0.3 and 1.9F) above normal in 2002 and 2003, respectively.

'Moonbeam' coreopsis. Compared to NP, NIL accelerated flowering of 'Moonbeam' coreopsis by 14 to 19 days, and promoted higher flower counts and quality ratings; however, plants were about 75% taller than those under NP (Tables 2 and 3). The higher quality rating of plants under NIL was primarily due to more flowers than on plants under NP, but was partially offset by taller plants. These results are consistent with a previous study in which 'Moonbeam' coreopsis grown under NIL flowered earlier, but were taller than plants under NP (14), and point out the possible need to control plant height under NIL.

Compared to plants grown under NP, plants treated with Cutless reached visible bud and first flower 9 to 19 days earlier, developed more flowers and flower buds, and had a similar or higher quality rating. However, all plants under NIL, except those treated with 150 ppm Cutless in 2002, were taller than those under NP, indicating that a higher concentration may be more effective in suppressing shoot growth. In contrast, 150 or 200 ppm Cutless was most effective in suppressing height of 'Moonbeam' coreopsis in a greenhouse study (15). Days to flower increased with increasing concentration in 2002, suggesting that higher concentrations may delay flowering, a common effect of many PGRs (1, 5, 15). Plants treated twice with B-Nine similarly flowered earlier with no effect of concentration, formed as many or more flowers, and had a higher quality rating than plants under NP. However, all plants under NIL, except those treated with either 5000 or 7500 ppm B-Nine in 2003, were taller than plants under NP. In contrast, greenhouse-grown 'Moonbeam' coreopsis treated with one application of 5100 ppm B-Nine (15) or 3 weekly applications of 5000 ppm B-Nine were consistently shorter than controls (11), suggesting lower efficacy of B-Nine when applied outdoors under nursery conditions than under greenhouse production regimes (7). Plants treated twice with 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel consistently flowered earlier than plants under NP and had similar or greater flower and flower bud counts, quality ratings, and plant heights. However, in 2003, time to flower increased by up to 5 days with increasing concentration, a response previously reported for greenhouse-grown 'Moonbeam' coreopsis (15). Bonzi concentration had no effect on any measured attribute, except for a slight reduction in flower and flower bud counts with increasing concentration, and all Bonzi-treated plants were taller than those under NP. Bonzi is primarily a root-absorbed PGR, and thus foliar sprays tend to be less effective than with some other PGRs (15). How-

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Table 2. Response of *Coreopsis verticillata* 'Moonbeam' to plant growth retardants when grown under night-interrupted lighting and nursery conditions in the southern United States, 2002.

Growth retardant	Concn. (ppm)	Days to visible bud[z]	Days to flower[z]	Flower number[y]	Plant height (cm)	Quality rating[x]
Cutless	50	60.7*[w]	78.0*	3.0*	36.1*	3.5*
	100	58.9*	76.2*	3.3*	32.1*	4.5*
	150	63.8*	83.3	2.5*	27.3	3.5*
Significance[v]		NS	NS	L**	L***	L*
B-Nine	2,500	60.6*	78.7*	3.0*	32.9*	4.0*
	5,000	60.6*	80.2*	3.5*	32.1*	4.3*
	7,500	60.1*	79.9*	3.0*	30.6*	4.0*
Significance		NS	NS	Q*	L***	NS
B-Nine/ Cycocel	2,500/1,500	60.4*	80.1*	3.5*	31.0*	4.3*
	5,000/1,500	59.2*	77.7*	3.0*	26.8	4.0*
	7,500/1,500	59.3*	77.3*	3.0*	25.1	4.0*
Significance		NS	NS	L**	L***	L*
Bonzi	50	60.6*	78.4*	3.5*	39.7*	4.0*
	100	58.2*	76.8*	3.3*	39.5*	4.0*
	150	60.8*	79.5*	3.0*	38.2*	4.0*
Significance		NS	NS	L*	NS	NS
NIL	—	59.8*	76.9*	3.8*	40.6*	4.5*
NP	—	74.4	91.6	1.5	23.7	2.5

[z]Beginning at the start of night-interrupted lighting (NIL), February 1, 2002.

[y]Flower and flower bud scale: 1 = 0, 2 = 1 to 50, 3 = 51 to 100, 4 = 101 to 150, and 5= > 150 flowers and flower buds per plant. Median values are reported.

[x]Quality rating: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower number; 4 = medium green foliage, less stem elongation and a larger plant with more flowers and flower buds than those ranked '3'; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower rankings. Median values are reported.

[w]Means followed by an asterisk are significantly different from the natural photoperiod (NP) control; $\alpha = 0.05$.

[v]Non-significant (NS) or significant linear (L) or quadratic (Q) response at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NIL controls included in trend analysis.

Table 3. Response of *Coreopsis verticillata* 'Moonbeam' to plant growth retardants when grown under night-interrupted lighting and nursery conditions in the southern United States, 2003.

Growth retardant	Concn. (ppm)	Days to visible bud[z]	Days to flower[z]	Height (cm)	Flower number[y]	Quality rating[x]
Cutless	50	47.3*[w]	73.2*	41.6*	3.0*	4.0*
	100	47.2*	75.4*	41.3*	3.0*	4.0
	150	43.6*	71.6*	39.6*	3.0*	4.0*
Significance[v]		NS	NS	L**	NS	NS
B-Nine	2500	50.7	74.2*	37.2*	3.0*	4.0*
	5000	46.2*	72.0*	33.6*	3.0*	4.0*
	7500	45.6*	75.0*	32.4	2.0	4.0*
Significance		NS	NS	L***	L*	NS
B-Nine/Cycocel	2500/1500	42.3*	73.6*	35.8*	3.0*	4.0*
	5000/1500	48.0*	77.7*	30.7	2.0	3.5
	7500/1500	46.4*	77.2*	30.6	3.0*	3.5
Significance		NS	L*	L***	NS	L*
Sumagic	20	46.3*	70.0*	35.8*	3.0*	4.0*
	40	45.4*	73.2*	31.6	3.0*	4.0*
	60	50.3*	77.0*	31.7	3.0*	4.0*
Significance		NS	L*	L***	NS	NS
NIL	—	46.1*	71.8*	48.1*	3.0*	4.0*
NP	—	61.6	91.4	27.3	2.0	3.5

[z]Beginning at the start of night-interrupted lighting (NIL), February 1, 2002.

[y]Flower and flower bud scale: 1 = 0, 2 = 1 to 50, 3 = 51 to 100, 4 = 101 to 150, and 5 = > 150 flowers and flower buds per plant. Median values are reported.

[x]Quality rating: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower number; 4 = medium green foliage, less stem elongation and a larger plant with more flowers and flower buds than those ranked '3'; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower rankings. Median values are reported.

[w]Means followed by an asterisk are significantly different from the natural photoperiod (NP) control; $\alpha = 0.05$.

[v]Non-significant (NS) or significant linear (L) response at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NIL controls included in trend analysis.

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ever, height of greenhouse-grown 'Moonbeam' coreopsis was suppressed by 60 and 120 ppm Bonzi (15), suggesting reduced activity outdoors (7). Plants treated with Sumagic, a triazole PGR closely related to Bonzi, flowered earlier than plants under NP, although time to flower increased by up to 5 days with increasing concentration, had similar or greater flower and flower bud counts, and similar quality ratings. In contrast to a lack of height control from Bonzi, plants treated with 40 or 60 ppm Sumagic were similar in height to those under NP and 34% shorter than NIL controls. Greater activity of Sumagic at lower concentrations than of Bonzi has been previously reported for several species (9, 10).

Compared to plants grown under NP, NIL accelerated days to visible bud and flower, increased flower and flower bud counts and plant height, and increased quality ratings of 'Moonbeam' coreopsis. In general, PGRs had little or no effect on time to flower, flower and flower bud counts, or quality ratings of plants grown under NIL. Plant growth regulator effects on plant height varied with PGR, concentration, and year. Height of plants under NIL and treated with all PGRs, except Bonzi, decreased linearly with increasing concentration. However, only plants treated with 150 ppm Cutless in 2002, but not in 2003; with 5000 or 7500 ppm B-Nine in 2003, but not in 2002; with 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel in both years; and with 40 or 60 ppm Sumagic were similar in height to plants under NP. No Bonzi concentration resulted in plant heights similar to those under NP. That Cutless and B-Nine were ineffective in controlling plant height in 1 of 2 years suggests that 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel, or 40 or 60 ppm Sumagic may be better choices in suppressing shoot growth of 'Moonbeam' coreopsis when grown under NIL.

'Goldsturm' coneflower. Times to visible bud and flower of 'Goldsturm' coneflower controls under NIL decreased by 50 days in 2002 and by 43 days in 2003 when compared to those under NP (Tables 4 and 5), indicating a greater effect of NIL on time to flower of later-blooming perennials than on early-blooming long-day perennials like 'Moonbeam' coreopsis. These accelerated times to flower are similar to those previously reported for 'Goldsturm' coneflower grown outdoors under NIL (13). Night-interrupted lighting controls also had formed more flowers and flower buds, had higher quality ratings, and were about 50% taller than plants under NP at first flower in 2002, but not in 2003. Differences in plant responses in 2002 and 2003 are consistent with those reported in 1999 and 2000, when flower and flower bud counts and plant height of plants under NIL were greater than those of plants under NP in one year, but not the other (13), and may reflect year-to-year differences in environmental conditions, especially temperatures, under nursery conditions (Table 1) or differences in potting dates. Plants in the first experiment were repotted from plug flats on November 1, 2001, whereas those in the second experiment were repotted on December 13, 2002, about 5 weeks later. A later potting date resulted in a shorter period of vegetative growth before plants were placed under photo-inductive NIL and probably contributed to fewer flowers on NIL controls in 2003 than in 2002 (10.5 vs. 26.5) and shorter plants [41.8 vs 56.4 cm (16.5 vs 22.2 in)]. Year-to-year differences in plant height and flower counts were not as apparent with 'Moonbeam' coreopsis controls under NIL as with 'Goldsturm' coneflower, possibly because of earlier flowering of coreopsis.

Plants grown under NIL and treated with all PGR types and concentrations reached visible bud and first flower earlier than plants grown under NP (Tables 4 and 5). However, increasing concentrations of Cutless, B-Nine, and B-Nine/Cycocel mixes, but not Bonzi or Sumagic, delayed time to visible bud, flower, or both in at least 1 of the 2 years tested. Delays in flowering of many species have been reported in response to plant growth regulators (1, 5, 15); however, neither Bonzi nor Sumagic affected flowering time of *Verbena rigida* Spreng. (10). Even with these delays, time to visible bud of plants treated with these PGRs was accelerated by 43 to 50 days in 2002 (Sumagic was not included in 2002) and by 22 to 39 days in 2003. This earlier flowering could greatly expand the marketing windows of 'Goldsturm' coneflower, which typically doesn't flower until late June or July in the lower South.

Bonzi concentration had no effect on any of the measured attributes in 2002, the only year it was evaluated, other than a higher quality rating of plants treated with 50 ppm Bonzi compared to plants under the NP. Bonzi was similarly ineffective in controlling height of greenhouse-grown 'Goldsturm' coneflower, although concentrations were not identified (25), and Latimer et al. (17) reported that greater than 160 ppm Bonzi was necessary for height control of this cultivar. Flower counts of plants treated with all PGR types and concentrations in 2002, except 2500 ppm B-Nine, were higher than those of plants under NP, and increased with increasing concentrations of B-Nine and B-Nine/Cycocel mixes (Table 4). In contrast, flower counts were similar among plants in all treatments in 2003 (Table 5). A mixed effect of PGRs on flower formation was not unexpected considering their effects on other crops (1, 6, 7, 10, 11, 15, 16, 23).

In 2002, plants treated with all PGRs were taller than plants grown under NP, and only B-Nine/Cycocel concentration minimally affected height. In contrast, increasing concentrations of all PGRs suppressed plant height linearly in 2003. Plants treated with 100 or 150 ppm Cutless twice, 7500 ppm B-Nine/1500 ppm Cycocel twice, or with 40 or 60 ppm Sumagic once in 2003 were shorter than plants grown under NP, whereas plants treated with other concentrations of these PGRs and all concentrations of B-Nine were similar in plant height to plants grown under NP. Height growth of 'Goldsturm' coneflower was unresponsive to 4 weekly applications of B-Nine, a single application of 160 ppm Bonzi, but responsive to an application of 30 ppm Sumagic; growing conditions were not identified (17). Greater suppression of height growth in 2003 probably was due, in part, to an additional application of Cutless and B-Nine made in 2003 and to Sumagic having greater activity than Bonzi (9, 10). However, NIL controls averaged 56.4 cm (22.2 in) in height in 2002 and 41.8 cm (16.5 in) in 2003, whereas NP controls averaged about 38 cm (15.0 in) in height in both years. These height differences in NIL controls suggest that other factors, including possibly environmental conditions and potting date, affected results in the two experiments. While other weather parameters were not recorded, temperatures differed widely between the two experiments, being below normal in February and March 2002 and above normal in the same period in 2003 (Table 1). Temperature is a critical factor controlling plant development processes, including vegetative and reproductive growth rates (19, 24).

Quality ratings of all plants grown under NIL, regardless of whether they were treated with a PGR, were similar to or

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Table 4. Response of *Rudbeckia fulgida* 'Goldsturm' to plant growth retardants when grown under night-interrupted lighting and nursery conditions in the southern United States, 2002.

Growth retardant	Concn. (ppm)	Days to visible bud[z]	Days to flower[z]	Flower number	Plant height (cm)	Quality rating[y]
Cutless	50	73.6*[x]	101.6*	24.1*	59.1*	4.0
	100	75.0*	101.6*	26.1*	57.7*	4.0
	150	78.4*	101.6*	24.3*	56.4*	4.5*
Significance[w]		L***	NS	NS	NS	NS
B-Nine	2,500	73.8*	102.8*	22.7*	58.2*	3.8
	5,000	78.5*	105.3*	30.2*	54.9*	4.5*
	7,500	79.1*	105.2*	33.3*	57.9*	4.5*
Significance		L***	L**	L**	NS	Q*
B-Nine/Cycocel	2,500/1,500	76.6*	103.6*	28.5*	50.7*	4.5*
	5,000/1,500	80.3*	108.8*	30.5*	45.3*	4.5*
	7,500/1,500	81.3*	109.6*	33.1*	49.1*	4.5*
Significance		L***	L***	NS	Q**	NS
Bonzi	50	73.0*	100.1*	27.4*	59.7*	4.5*
	100	73.4*	101.0*	24.3*	58.7*	4.3
	150	73.4*	101.0*	24.9*	59.7*	4.3
Significance		NS	NS	NS	NS	NS
NIL	—	73.9*	102.2*	26.5*	56.4*	4.5*
NP	—	124.2	150.5	15.7	37.7	4.0

[z]Beginning at the start of night-interrupted lighting (NIL), February 1, 2002.

[y]Quality rating: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower number; 4 = medium green foliage, less stem elongation and a larger plant with more flowers and flower buds than those ranked '3'; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower rankings. Median values are reported.

[x]Means followed by an asterisk are significantly different from the natural photoperiod (NP) control; $\alpha = 0.05$.

[w]Non-significant (NS) or significant linear (L) or quadratic response at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NIL controls included in trend analysis.

Table 5. Response of *Rudbeckia fulgida* 'Goldsturm' to plant growth retardants when grown under night-interrupted lighting and nursery conditions in the southern United States, 2003.

Growth retardant	Concn. (ppm)	Days to visible bud[z]	Days to flower[z]	Height (cm)	Flower number	Quality rating[y]
Cutless	50	75.7*[x]	102.7*	34.2	12.8	4.0
	100	86.6*	109.6*	29.6*	11.5	4.0
	150	80.5*	108.7*	28.8*	13.5	4.0
Significance[w]		NS	NS	L***	NS	NS
B-Nine	2500	70.9*	98.1*	38.5	16.0	4.0
	5000	72.7*	100.5*	34.7	15.3	4.0
	7500	85.9*	111.0*	33.5	14.0	4.0
Significance		Q*	Q*	L***	Q*	Q*
B-Nine/Cycocel	2500/1500	72.0*	97.4*	37.1	15.0	4.0
	5000/1500	80.3*	105.0*	33.2	13.9	4.0
	7500/1500	89.0*	115.0*	32.1*	14.0	4.0
Significance		NS	NS	L***	NS	NS
Sumagic	20	72.3*	97.6*	34.6	19.3*	4.5*
	40	78.6*	103.2*	29.4*	13.0	4.5*
	60	83.9*	109.6*	30.4*	13.1	4.0
Significance		NS	NS	L***	Q*	Q**
NIL	—	75.2*	104.0*	41.8	10.5	3.8
NP	—	116.5	145.2	37.5	13.1	4.0

[z]Beginning at the start of night-interrupted lighting (NIL), February 1, 2003.

[y]Quality rating: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant, minimal flowers; 3 = light green foliage, excessive stem elongation or small plant, reduced flower number; 4 = medium green foliage, less stem elongation and a larger plant with more flowers and flower buds than those ranked '3'; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower rankings. Median values are reported.

[x]Means followed by an asterisk are significantly different from the natural photoperiod (NP) control; $\alpha = 0.05$.

[w]Non-significant (NS) or significant linear (L) or quadratic (Q) response at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). NIL controls included in trend analysis.

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higher than those of plants under NP in both years. In 2002, these results were primarily due to increased flower and flower bud counts on plants under NIL, even though these plants were taller than those under NP. In contrast, similar or higher quality ratings of plants under NIL in 2003 were due to height suppression by all PGRs, resulting in plants similar to or shorter than those under NP, without affecting flower and flower bud counts.

Results of this study indicate that NIL accelerated flowering of 'Moonbeam' coreopsis and 'Goldsturm' coneflower, two long-day herbaceous perennials, when grown outdoors in the southern United States, without adversely affecting flower and flower bud counts or plant quality. However, plants grown under NIL generally were taller than plants grown under NP, probably due to the incandescent light source. When several PGRs were applied to plants under NIL, results varied with species, PGR type, concentration, and year. Height of 'Moonbeam' coreopsis was effectively suppressed by 5000 or 7500 ppm B-Nine + 1500 ppm Cycocel in both years, and with 40 or 60 ppm Sumagic in the one year it was tested. Higher concentrations of Cutless and B-Nine suppressed height growth in 1 of 2 years, while Bonzi was ineffective in the 1 year it was tested. None of the PGR types or concentrations suppressed height growth of 'Goldsturm' coneflower to the level of those under NP in 2002. However, in 2003, applications of Cutless, B-Nine, B-Nine/Cycocel, and Sumagic all resulted in heights similar to or less than those under NP. The greater height control in 2003 probably was related to one or more of the following: the later potting date of plugs in the second experiment, to the additional application of Cutless and B-Nine, and to temperature differences during the two experiments. While year-to-year differences in height control occurred, results indicated that of the PGRs tested, multiple applications of 5000 or 7500 ppm B-Nine/1500 ppm Cycocel mixes or single applications of 40 or 60 ppm Sumagic were most effective in suppressing height growth of 'Moonbeam' coreopsis and 'Goldsturm' coneflower when timed to periods of rapid shoot elongation.

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