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Limited Inductive Photoperiod Affects Herbaceous Perennials Grown Under Nursery Conditions in the Southern United States¹

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Abstract

A study was conducted to determine if limited inductive photoperiod (LIP) initiated in late winter could be used to control stem elongation in 'Goldsturm' coneflower (*Rudbeckia fulgida* 'Goldsturm'), 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam'), or 'Early Sunrise' coreopsis (*Coreopsis grandiflora* 'Early Sunrise'), grown outdoors under nursery conditions in the southern United States, without negating the benefits of earlier flowering from night-interrupted lighting (NIL). Treatments were NIL beginning on February 1 and ending on February 15, March 1, March 15, or April 1, 2002, plus a natural photoperiod (NP) treatment. The experiment was repeated in 2003 with the inclusion of an additional NIL treatment ending on April 15. LIPs of at least 15 to 30 days, 30 to 45 days, and 30 to 45 days promoted earlier flowering of 'Early Sunrise' coreopsis, 'Moonbeam' coreopsis, and 'Goldsturm' coneflower, respectively. Flower counts and quality ratings of the three cultivars that received LIPs were similar to or higher than those of plants under a NP, except for a reduction in flowering and quality ratings of 'Goldsturm' coneflower exposed to LIPs ending on March 1 and March 15, 2002, and on March 1, 2003, and later. LIP effects on plant height were mixed, although there was at least one duration of LIP that resulted in earlier flowering of the three cultivars and plants similar to or shorter than plants under a NP.

Index words: Night-interrupted lighting, flower induction, long-day plant, container production.

Species used in this study: 'Goldsturm' coneflower (*Rudbeckia fulgida* Ait. 'Goldsturm'); 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam'); 'Early Sunrise' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Early Sunrise').

Significance to the Nursery Industry

Herbaceous perennials can be forced to flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod. Growers in the southern United States

may have a similar opportunity for early forcing by exposing plants to night-interrupted lighting (NIL) outdoors from 10 p.m. to 2 a.m. However, NIL from incandescent lamps can promote excessive shoot elongation. Limited inductive photoperiod (LIP), a concept of photoperiod inhibition in which plants are given a limited number of inductive cycles to initiate flowering, promotes flowering, but bolting-related stem elongation stops upon re-exposure to noninductive conditions. LIPs of at least 15 to 30 days, 30 to 45 days, and 30 to 45 days outdoors under nursery conditions promoted earlier flowering of 'Early Sunrise' coreopsis, 'Moonbeam'

¹Received for publication April 1, 2008; in revised form April 14, 2008.

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The *Journal of Environmental Horticulture* (ISSN 0738-2898) is published quarterly in March, June, September, and December by the Horticultural Research Institute, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005. Subscription rate is \$65.00 per year for scientists, educators and ANLA members; \$95.00 per year for libraries and all others; add \$25.00 for international (including Canada and Mexico) orders. Periodical postage paid at Washington, DC, and at additional mailing offices. POSTMASTER: Send address changes to *Journal of Environmental Horticulture*, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005.

coreopsis, and ‘Goldsturm’ coneflower, respectively. The acceleration of flowering was similar to that reported when these same cultivars were exposed to NIL outdoors beginning February 1 and continuing until first flower (9, 10). LIPs that resulted in earlier flowering did not always promote plant compaction, although there was at least one duration of LIP that resulted in earlier flowering of the three cultivars and plants similar to or shorter than plants under a NP. LIP outdoors under nursery conditions has potential as a tool for promoting compactness of herbaceous perennials; however, the duration will affect time to flower, possibly negating the benefit of earlier flowering under NIL.

Introduction

Flowering is controlled by internal and external factors, including exposure to low temperatures (vernalization) and photoperiod (3, 17, 19). Vernalization promotes flowering at subsequent higher temperatures (18), and even when vernalization is not required for flowering, many herbaceous perennials benefit from cold exposure by earlier or improved flowering (1, 2, 4). 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) (1, 2, 4), including the qualitative LDPs, ‘Moonbeam’ coreopsis (*Coreopsis verticillata* ‘Moonbeam’) (8), ‘Early Sunrise’ coreopsis (*Coreopsis grandiflora* ‘Early Sunrise’), and ‘Goldsturm’ coneflower (*Rudbeckia fulgida* ‘Goldsturm’) (22). In quantitative LDPs, long days are not required to induce flowering but are beneficial in either hastening the rate of flowering or increasing the number of flowers (1, 2).

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 is lacking. 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 51 to 75 days in 2000 compared to plants grown under a NP (9). NIL accelerated time to flower and increased flower counts of ‘Moonbeam’ coreopsis by 7 to 36 days and 20 to 244% and of ‘Early Sunrise’ coreopsis by 3 to 20 days and 26 to 64%, respectively (10). However, ‘Goldsturm’ coneflower under NIL were 18 to 23% (1999) and 48 to 52% (2000) taller than plants under a NP at anthesis and plant quality rating was lower in both years. Similarly, ‘Moonbeam’ and ‘Early Sunrise’ coreopsis under NIL were up to 155 and 46%, respectively, taller than plants under NP.

Based on studies with *Rudbeckia bicolor* (syn. with *R. hirta* var. *pulcherima* Farw.), Murneek (13) reported the effects of day length on stem elongation and flowering as distinctly separate. Results indicated LDPs require a certain number of days of critical photoperiod to initiate reproductive growth, whereas stem elongation could not be induced but occurs and is sustained only under long photoperiods

(LDs). Limited inductive photoperiod (LIP), an expansion of Murneek’s (13) concept of photoperiod inhibition, is a method of giving plants the minimum number of inductive cycles to initiate flowering before transfer back to noninductive conditions. LIP promotes flowering, but bolting-related stem elongation stops upon transfer back to SDs. *Rudbeckia hirta* ‘Marmalade’ that received only enough LDs for floral initiation were half as tall as plants held under LDs until anthesis (14). Similarly, LIP effectively controlled height of ‘Sunray’ and ‘Early Sunrise’ coreopsis by inhibiting stem elongation without affecting scape length or axillary floral bud number, although flowering was delayed compared to plants grown in continuous LDs (5, 6). The objective of this study was to determine if LIP could be used to control stem elongation of three LD herbaceous perennials grown outdoors under nursery conditions in the southern United States without negating the benefits of earlier flowering from NIL.

Materials and Methods

‘Goldsturm’ coneflower (*Rudbeckia fulgida* ‘Goldsturm’), ‘Moonbeam’ coreopsis (*Coreopsis verticillata* ‘Moonbeam’), and ‘Early Sunrise’ coreopsis (*Coreopsis grandiflora* ‘Early Sunrise’) were transplanted on November 28, 2001, from 72-cell flats (Green Leaf Perennials, Lancaster, PA) into 2.8 liter (#1 trade) containers of milled pine bark:peat (3:1, by vol) substrate. The growth medium was amended per m³ (yd³) 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) Micro-max (The Scotts Company). Coreopsis 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 watered as needed from overhead impact sprinklers. 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 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ over the NIL area. On February 1, 2002, forty plants of each cultivar were moved under NIL, and 10 plants of each species remained as unlighted controls. Ten plants of each cultivar were returned to a NP on February 15, March 1, March 15, and April 1, 2002; on these dates the NP was 11.1, 11.5, 12.0, and 12.5 h, respectively. Pots were spaced so that plant canopies did not overlap. Spacing varied among cultivars and increased as plants grew. 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 reached the first open flower stage. Plant cultivars

in the NIL and natural blocks were randomized as separate experiments, and all treatments were replicated with 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 number, 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 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds. Quality rating varied slightly among the three species 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 number; 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 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 done by one person.

The experiment was repeated the following winter using similar methodology except as noted below. Transplants of the three cultivars were repotted on December 12, 2002. In addition to treatments included in the first experiment, a treatment in which plants were transferred from NIL to NP on April 15, 2003, was included; on this date the NP was 12.9 h. At first flower, heights of 'Early Sunrise' coreopsis and 'Goldsturm' coneflower were recorded to the top of the tallest flower and to the uppermost leaf. Vegetative heights were used to calculate GI for these two cultivars. The vegetative height was not recorded for 'Moonbeam' coreopsis because uppermost leaves and flowers were at similar heights.

In both experiments, an analysis of variance was performed on data using SAS version 9.1.3 (SAS Institute, Cary, NC). The normality assumption for ANOVA was tested using the normality statistics from PRO UNIVARIATE (12). 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 GLM; days to visible bud, days to flower, and flower number 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; and quality rating was analyzed with PROC GENMOD using the multinomial probability distribution with a cumulative logit link. 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.

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 0.1C (0.3F) and 1.0C (1.9F) above normal in 2002 and 2003, respectively.

'Early Sunrise' coreopsis. Times to visible bud and first flower in 'Early Sunrise' coreopsis, a qualitative LDP (2, 4), increased linearly or quadratically in 2002 and 2003, with a range of about 6 days, as exposure to LIP decreased from 60 (April 1, 2002) or 75 days (April 15, 2003) to 15 days (February 1) (Tables 2 and 3). Plants exposed to LIP from February 1 until February 15 (2003) or March 1 (2002) and later flowered before plants under NP, 5 to 8 days earlier in 2002 and 5 to 11 days earlier in 2003. These results agree with previous LIP studies in which a continuation of photo-inductive cycles beyond the minimum for floral initiation promoted earlier flowering (7, 14). Flower counts increased as the LIP duration increased in 2002. Plants exposed to LIP until February 15 and April 1, 2002, formed 12 and 40% more flowers, respectively, than plants under a NP (Table 2). Similar increases in flowering were reported by Damaan and Lyons (6) and Warner (20) in response to increasing the number of photo-inductive cycles. In 2003, there was not a trend of increased flower counts with more photo-inductive cycles, and plants exposed to all LIP treatments, except the March 15 ending of LIP, formed between 26 and 35% more flowers than did plants under NP (Table 3).

Plant height decreased linearly in both years as the number of LIP cycles decreased. Plants exposed to LIP from February 1 until February 15 were about 20% shorter than those exposed to LIP until April 1, 2002, or April 15, 2003. These results are consistent with reports of a linear relationship between the number of LDs received and stem length at first flower in 'Sunray' and 'Early Sunrise' coreopsis (6). However, plants grown under LIP in 2002 were 16 to 51% taller than those under NP, while those exposed to LIP until March 15, 2003, or later were 22 to 31% taller. While often taller, plants exposed to all LIP treatments had a quality rating similar to that of plants under NP. All plants were considered highly marketable with a quality rating of ≥ 4.4 in both years.

'Moonbeam' coreopsis. Days to visible bud and first flower decreased linearly by about 12 and 14 days, respectively, as the LIP duration increased from 15 to 60 (2002) or 75 days (2003) (Tables 2 and 3). Plants exposed to LIP from February 1 until March 1 and later, except until April 1, 2003, reached visible bud quicker than plants under NP, while plants exposed to LIP until March 1 (2003) or March 15 (2002) or later

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

Month	Temperature [C (F)] ^a			
	2002	Departure	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)

^aTemperatures measured 1.5 m (5 ft) above ground.

^bDeparture from normal (30-year average); weather data provided by the NOAA, National Climatic Data Center.

Table 2. The effects of limited inductive photoperiods on growth and flowering of three herbaceous perennials in a nursery setting in 2002.

Treatment ^y	Days to visible bud ^x	Days to flower ^x	Flower number ^w	Height (cm)	Quality rating ^z				
					1 ^v	2	3	4	5
‘Early Sunrise’ coreopsis									
Natural	59	77	57	31.0	0	0	0	2	8
February 15	57	75	64*	36.3*	0	0	0	1	9
March 1	52* ^u	72*	66*	36.1*	0	0	0	0	10
March 15	52*	71*	71*	39.0*	0	0	0	0	10
April 1	50*	69*	80*	46.8*	0	0	0	2	8
Significance ⁱ	L***	L***	L***	L***			NS		
‘Moonbeam’ coreopsis									
Natural	82	101	1.8 ^s	26.0	0	1	7	2	0
February 15	75	94	1.7	22.6	0	0	9	1	0
March 1	72*	92	2.0	22.4	0	0	4	6	0
March 15	64*	82*	2.2*	20.1*	0	0	3	7	0
April 1	62*	80*	3.1*	33.1*	0	0	0	5	5
Significance	L***	L***	L***	Q***			L***		
‘Goldsturm’ coneflower									
Natural	126	153	13	39.5	0	0	6	4	0
February 15	125	154	19*	37.2	0	0	1	5	4
March 1	108*	129*	7*	31.5*	0	0	7	2	1
March 15	85*	105*	5*	26.0*	0	0	5	5	0
April 1	71*	90*	23*	54.8*	0	0	0	4	6
Significance	L***	L***	Q***	Q***			Q*		

^zQuality 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 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.

^yPlants exposed to night-interrupted lighting (NIL) between 10:00 pm and 2:00 am beginning on February 1 and ending on the date listed under ‘Treatment’; plants in the natural treatment were not exposed to NIL.

^xAnalysis using the negative binomial probability distribution and the Chi Square test statistic, $\alpha = 0.05$.

^wAnalysis using the Poisson probability distribution and the Chi Square test statistic, $\alpha = 0.05$.

^vAnalysis using the multinomial probability distribution and the Chi Square test statistic, $\alpha = 0.05$.

^uAn asterisk indicates a significant difference compared to the natural treatment using contrast statements, $\alpha = 0.05$.

ⁱNon-significant (NS) or significant linear (L) or quadratic (Q) trend at $\alpha = 0.05$ (*) or 0.001 (***) ; natural treatment not included in analysis.

^sFlowering rated on the following scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds.

flowered earlier. As with ‘Early Sunrise’ coreopsis, flowering, as measured by a flower and flower bud rating, decreased linearly as the LIP duration decreased. The flower and flower bud rating was higher for plants receiving LIP until at least March 15 than for plants under NP. This accelerated and enhanced flowering with increased photo-inductive cycles under nursery conditions agrees with previous greenhouse studies (7, 14, 20).

The effects of LIP on plant height differed in the two experiments. In both years, plants exposed to LIP until February 15 or March 1 were similar in height to plants under NP. However, plants grown under LIP until March 15 and April 1, 2002, were 23% shorter and 27% taller, respectively, than those under NP. In contrast, plant height increased linearly with LIP duration in 2003, with height of plants given LIP until April 15 more than twice that of plants under LIP until February 15. Plants grown under LIP until March 15 or later were 31 to 89% taller than plants under NP. The effects of LIP on plant height in 2002 were unexpected and do not appear to be related to plant differences at the beginning of the experiment, environmental conditions, or cultural practices. Plant

quality rating increased linearly in both years as duration of LIP increased, reflecting the higher number of flowers and flower buds on plants exposed to longer LIPs.

‘Goldsturm’ coneflower. Days to visible bud and flower in ‘Goldsturm’ coneflower decreased up to 54 and 64 days, respectively, in 2002 and up to 61 and 65 days in 2003 as LIP increased (Tables 2 and 3). Plants grown under LIP from February 1 until at least March 1, 2002, and March 15, 2003, flowered 24 to 63 days and 53 to 58 days, respectively, before plants under NP. This acceleration in flowering was three to five times that observed in ‘Early Sunrise’ and ‘Moonbeam’ coreopsis under LIP and can be attributed to the naturally later flowering of ‘Goldsturm’ coneflower. Relative to that of plants under NP, flowering was reduced by LIP extending until March 1 and March 15, 2002, but was increased by shorter and longer periods of LIP. In 2003, flowering was reduced by LIPs longer than 15 days, possibly due to an insufficient number of photo-inductive cycles for complete floral development, whereas plants exposed to LIP until February 15, 2003, appeared to behave similarly to plants under

Table 3. The effects of limited inductive photoperiods on growth and flowering of three herbaceous perennials in a nursery setting in 2003.

Treatment ^y	Days to visible bud ^x	Days to flower ^x	Flower number	Height (cm)	Quality rating ^z				
					1 ^w	2	3	4	5
‘Early Sunrise’ coreopsis									
Natural	46	73	34	32.8	0	0	0	1	9
February 15	42* ^v	68*	41	34.2	0	0	0	1	9
March 1	37*	66*	45*	33.4	0	0	0	1	9
March 15	37*	62*	40	40.0*	0	0	0	2	8
April 1	36*	61*	43*	42.4*	0	0	0	4	6
April 15	37*	62*	46*	43.1*	0	0	0	3	7
Significance ^u	Q*	L***	NS	L***			NS		
‘Moonbeam’ coreopsis									
Natural	61	88	1.6 ⁱ	24.7	0	0	9	1	0
February 15	53	84	1.6	22.0	0	0	7	2	0
March 1	48*	78*	1.8	25.4	0	1	3	6	0
March 15	45*	69*	2.0*	32.4*	0	0	1	9	0
April 1	56	72*	2.8*	43.4*	0	0	0	7	3
Significance	L*	L***	L***	L***			L***		
‘Goldsturm’ coneflower									
Natural	119	147	14	42.3	0	0	0	9	1
February 15	128	157	13	39.3	0	0	0	8	1
March 1	130	154	9*	34.7*	0	0	4	5	0
March 15	67*	89*	10*	34.6*	0	0	1	8	0
April 1	73*	94*	8*	44.6	0	0	5	3	0
April 15	69*	92*	11*	41.4	0	0	3	5	0
Significance	C***	C**	Q*	C**			Q**		

^zQuality 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 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.

^yPlants exposed to night-interrupted lighting (NIL) between 10:00 pm and 2:00 am beginning on February 1 and ending on the date listed under ‘Treatment’; plants in the natural treatment were not exposed to NIL.

^xAnalysis using the negative binomial probability distribution and the Chi Square test statistic, $\alpha = 0.05$.

^uAnalysis using the multinomial probability distribution and the Chi Square test statistic, $\alpha = 0.05$.

^vPaired comparison to the natural treatment using contrasts, $\alpha = 0.05$.

^wNon-significant (NS) or significant linear (L), quadratic (Q), or cubic (C) trend at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***); natural treatment not included in analysis.

ⁱFlowering rated on the following scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds.

NP. The minimum number of inductive cycles for normal development and anthesis in *Rudbeckia* were reported to depend on factors such as length and duration of LD, plant age when exposed to LD, duration of experimental observations, and what apical developments were used as criteria for the transition to flowering (11). Another possible factor contributing to the year-to-year differences may have been environmental conditions, especially temperatures, under nursery conditions (Table 1).

As with ‘Moonbeam’ coreopsis in 2002, LIPs intermediate in length reduced height of ‘Goldsturm’ coneflower relative to that of plants under a NP. Plants grown under LIP until March 1 and March 15 were 20 and 34% shorter, respectively, in 2002 and about 18% shorter in 2003 than those under NP. Plants exposed to longer periods of LIP were either similar in height (2003) to plants under NP or taller (39% in 2002).

Quality rating response to LIP differed in the two years. Quality rating was higher for plants exposed to LIP until February 15 or April 1, 2002, than for plants in other treatments, reflecting higher flower counts. In 2003, quality rating was

higher for plants under NP or exposed to LIP until February 15 than for plants grown under longer LIPs, again reflecting higher flower numbers and a failure to flower of two plants receiving LIP until March 15 and three plants each receiving LIP until April 1 and April 15.

LIP under nursery conditions promoted earlier flowering of ‘Early Sunrise’ coreopsis, which concurs with an earlier nursery study in which the initiation of NIL was staggered but continued until coreopsis flowered (10). However, results were mixed when the number of inductive cycles was reduced. In 2002, none of the LIP treatments resulted in plants that were as short as those under NP and flowered earlier, although flower counts increased under all LIPs. In 2003, LIP ending February 15 or March 1 resulted in earlier flowering, more flowers (March 1 only), and plants similar in height to those under NP. While these results with ‘Early Sunrise’ coreopsis differed in the two experiments, the quality rating was similarly high for plants under LIP and a NP in both experiments, suggesting there may be a market advantage gained through earlier flowering under LIP.

LIP of at least 30 (2003) or 45 days (2002) accelerated flowering, increased flower and flower bud counts, and enhanced plant quality of 'Moonbeam' coreopsis, compared to shorter periods of LIP or exposure to NP. In each experiment, there was only one duration of LIP that resulted in earlier flowering and plants similar in height or shorter than plants under a NP, 30 days (March 1, 2003) and 45 days (March 15, 2002). While the naturally early flowering of 'Early Sunrise' coreopsis limited the acceleration of flowering under LIP to 8 days, 'Moonbeam' coreopsis flowered up to 3 weeks earlier under LIP and plant quality rating was higher than that of plants under NP.

Exposure of 'Goldsturm' coneflower to LIP from February 1 until March 1 (2002), March 15 (2002 and 2003), or April 1 (2003) promoted earlier flowering and suppressed plant height (except with April 1, 2002) relative to flowering and height of plants under NP. While these periods of LIP achieved our objective, flowering was reduced resulting in lower quality ratings in 2003, but not 2002, than those of plants under NP. Even with the reduced quality ratings under LIP, there may be marketing opportunities. 'Goldsturm' coneflower naturally flowers in mid to late summer in the southeastern United States, long after the peak marketing period in spring. However, by exposing plants to LIPs from February 1 until March 15 or April 1, plants reached visible bud by April 15 and first flower by early May. Shorter periods of LIP resulted in progressively later flowering; thus, it may be possible to obtain budded plants in April and successive crops in peak flower from early May until the plant's natural flowering period in July and August.

Consistent among the three cultivars is a year-to-year variation in the results, likely due in part to differences in environmental conditions. 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 rates of vegetative and reproductive growth (15, 21).

In summary, LIPs of at least 15 to 30 days, 30 to 45 days, and 30 to 45 days outdoors under nursery conditions promoted earlier flowering of 'Early Sunrise' coreopsis, 'Moonbeam' coreopsis, and 'Goldsturm' coneflower, respectively. The acceleration of flowering was similar to that reported when these same cultivars were exposed to NIL outdoors beginning February 1 and continuing until first flower (9, 10) or when other species received LIP under greenhouse conditions (5, 6, 7, 12). Flower counts from the three cultivars that received LIPs were similar to or higher than those of plants under a NP, except for a reduction in flowering of 'Goldsturm' coneflower in several LIP treatments. Effects of LIPs on plant height were mixed, although there was at least one duration of LIP that resulted in earlier flowering of the three cultivars and plants similar to or shorter than plants under NP. While the three cultivars used in this study are in the same family, Asteraceae, previous studies using NIL (9, 10) have shown similar responses from herbaceous perennials in other families. Thus, it is unlikely these results are unique to Asteraceae.

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