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Night-Interrupted Lighting Accelerates Flowering of Herbaceous Perennials Under Nursery Conditions in the Southern United States[1]

Gary J. Keever[2], J. Raymond Kessler, Jr.[3] and James C. Stephenson[4]
Department of Horticulture
Auburn University, AL 36849

Abstract

Night-interrupted lighting (NIL) outdoors in a southern nursery setting was evaluated as a system for accelerated production of herbaceous perennials requiring long days to flower. Treatments were NIL beginning February 1, February 15, March 1, or March 15, and a natural photoperiod control. Compared to plants under the natural photoperiod and depending upon initiation of NIL treatment and year, NIL accelerated and increased flowering of 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') 7 to 36 days and 20 to 244%, 'Early Sunrise' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Early Sunrise') 3 to 20 days and 26 to 64%, 'Sunray' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Sunray') 6 to 13 days and 21 to 44%, 'Autumn Joy' stonecrop (*Sedum* x 'Autumn Joy') 26 to 57 days and 200 to 300%, and 'Blue Queen' salvia (*Salvia* x*superba* Stapf 'Blue Queen') 7 to 12 days and 56 to 83%. Flowering of 'Red Beauty' obedient plant (*Physostegia virginiana* (L.) Benth. 'Red Beauty) was accelerated 20 to 54 days; however, inflorescence counts decreased 38 to 46% in one year and was not affected by treatments in the second year. Plants of all cultivars, except 'Autumn Joy' sedum and 'Red Beauty' obedient plant, were taller when exposed to NIL than when grown under the natural photoperiod, however plant quality rating of all cultivars was as high or higher under NIL.

Index words: Night-interrupted lighting, photoperiod, herbaceous perennials, container production.

Species used in this study: 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam'); 'Early Sunrise' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Early Sunrise'); 'Sunray' coreopsis (*Coreopsis grandiflora* Hogg ex Sweet. 'Sunray'); 'Autumn Joy' stonecrop (*Sedum* L. x 'Autumn Joy'); 'Red Beauty' obedient plant (*Physostegia virginiana* (L.) Benth. 'Red Beauty); 'Blue Queen' salvia (*Salvia* x*superba* Stapf 'Blue Queen').

Significance to the Nursery Industry

Herbaceous perennials can be forced into flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod. While outdoor environmental conditions in the southern United States can be unpredictable, mild winter and early spring temperatures promote root and shoot growth under naturally short days. These conditions provide nurserymen an opportunity to accelerate flowering of long-day herbaceous perennials by exposing plants to night-interrupted lighting (NIL) outdoors from 10 pm to 2 am beginning as early as February 1. NIL stimulated earlier flowering of 'Moonbeam', 'Early Sunrise' and 'Sunray' coreopsis, 'Autumn Joy' sedum, 'Red Beauty' obedient plant, and 'Blue Queen' salvia and increased flower and flower bud production of all cultivars, except 'Red Beauty' obedient plant. A potential limitation to using incandescent lamps as the source of NIL, whether indoors or outdoors, is increased plant height, observed in all species in this study, except 'Autumn Joy' sedum and 'Red Beauty' obedient plant. However, plant quality of plants exposed to NIL was as high or higher than that of plants under the natural photoperiod. By staggering the initiation of long days outdoors under nursery conditions in the southern United States, growers have the potential to provide successive crops in peak bloom from spring to the plants' natural flowering period, thus expanding the marketing window and market quality of these and other long-day herbaceous perennials.

[1]Received for publication June 29, 2005; in revised form October 21, 2005.

[2]Professor.

[3]Associate Professor.

[4]Associate Superintendent, Ornamental Horticulture Substation, Mobile, AL.

Introduction

Herbaceous perennials are most marketable when in flower, especially when flowering occurs in spring to early summer, the peak garden plant market period for much of the United States. However, many of the most popular herbaceous perennials naturally flower during other times of the year.

Flowering is controlled by internal and external factors, including exposure to low temperatures and photoperiod (3, 9, 12, 13). Vernalization is a cold temperature treatment that promotes flowering at subsequent higher temperatures (3, 12). 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) with a minimum of 10 foot-candles from 10:00 pm to 2:00 am generally is recommended to induce flowering of long-day plants (LDPs) (1, 2, 4), including the qualitative LDPs, *Coreopsis verticillata* 'Moonbeam' (2, 4, 7), *Coreopsis grandiflora* 'Early Sunrise' (2, 4), *Physostegia virginiana* (2, 4, 5), and *Sedum* x 'Autumn Joy' (11). 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). Quantitative long-day herbaceous perennials include *Coreopsis grandiflora* 'Sunray' (4) and *Salvia* x 'Blue Queen' (4). All of the cited research related to photoperiod manipulation was conducted in greenhouses or in growth chambers under climate controlled conditions.

Most herbaceous perennials sold by nurseries in the southeastern United States are potted in fall or winter for spring or summer sales. While photoperiod manipulation under green-

house conditions is an alternative, most nurseries in the southeastern U.S. lack facilities for this procedure. The nursery industry in coastal states of the South is primarily in USDA cold hardiness zone 8. Cool nights and mild days in late winter provide ideal conditions for growth of many herbaceous perennials. In a previous study (8), NIL used outdoors accelerated flowering of 'Goldsturm' coneflower (*Rudbeckia fulgida* Ait. 'Goldsturm') and 'Coronation Gold' yarrow (*Achillea* x 'Coronation Gold'), both qualitative LDPs, by 26–75 days and 2–11 days, respectively, compared to flowering under natural photoperiod. NIL also increased flower and flower bud counts in 'Coronation Gold' yarrow (up to 100%), 'Butterfly Blue' scabiosa (*Scabiosa columbaria* L.) (44–51%), and 'Alaska' shasta daisy (*Leucanthemum* x*superbum* Bergmans ex. J. Ingram 'Alaska') (100–151%). This study is a continuation of our earlier study to determine the effectiveness of NIL initiated on different dates on flowering of selected qualitative or quantitative LD, herbaceous perennials grown outdoors in the southeastern U.S.

Materials and Methods

Three experiments were conducted in 1999, 2000, and 2001 using six cultivars of herbaceous perennials, all of which were used in two of the three years, except 'Moonbeam' coreopsis which was used in all three years. All perennials, except 'Moonbeam' coreopsis, were purchased as plugs from a commercial source (Green Leaf Perennials, Lancaster, PA) and were 3 to 5 cm (1.2 to 2.0 in) tall when transplanted. 'Moonbeam' coreopsis were rooted from terminal cuttings and were about 5 cm (2.0 in) tall when transplanted.

1999 study. Fifty transplants each of 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam'), 'Red Beauty' obedient plant (*Physostegia virginiana* (L.) Benth. 'Red Beauty'), and 'Autumn Joy' sedum (*Sedum* L. x 'Autumn Joy') were transplanted on December 18, 1998, from 72-cell flats into 2.8 liter (#1 trade) containers of pine bark:peat (3:1, by vol). 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). Plants were grown pot-to-pot outdoors in full sun through the winter under natural photoperiods 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. Plans were to cover plants with white polyethylene if temperatures approaching –6.7C (20F) were predicted. As the season progressed and plants grew, the minimum temperature for protection was increased. However, in neither 1999 nor 2000 was protection necessary.

A night-interrupted lighting (NIL) block was established outdoors in the nursery area to provide a minimum of 10 foot-candles of light from 10:00 pm to 2:00 am. 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 (PAR) at plant height averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NIL area. Ten plants of each species were moved from an adjacent unlighted block into the NIL block on February 1, February 15, March 1, and March 15, 1999; on these dates the natural photoperiod was 10.74, 11.12, 11.53, and 11.97 h, respectively. Ten plants of each species remained under natural photoperiod. After the initiation of lighting treatments, pots were spaced so that plant canopies did not overlap. Spacing varied with species 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 pm daily and removed at 8:00 am daily beginning February 1 and continuing until all plants reached the first open flower stage. Plant species in the NIL block were randomized as separate experiments; however, because of the nature of the treatments, plants under a natural photoperiod were not randomized. Plants in all treatments were replicated with 10 single plants.

The date of the first fully-opened flower was recorded. At this time, flower (inflorescence) and floral bud count, plant height from the substrate surface to the uppermost plant part, growth index [(height + widest width + width perpendicular to widest width) ÷ 3], and quality rating were determined. Quality rating varied slightly among the 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: height, fullness, foliage 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 the same person.

2000 study. The experiment was repeated the following winter using similar methodology except as noted below. Transplants of 'Moonbeam' coreopsis, 'Early Sunrise' coreopsis (*Coreopsis grandiflora* 'Early Sunrise'), 'Sunray' coreopsis (*Coreopsis grandiflora* 'Sunray'), and 'Blue Queen' *(Salvia* x*superb*a Stapf ' Blue Queen') were potted on December 8, 1999. Rather than actual flower and flower bud counts, flowering of 'Moonbeam' coreopsis was rated on the following scale in 2000 and 2001: 1 = 0, 2 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds.

2001 study. Transplants of 'Moonbeam' coreopsis, 'Early Sunrise' coreopsis, 'Sunray' coreopsis, 'Red Beauty' obedient plant, 'Blue Queen' salvia, and 'Autumn Joy' sedum were potted on December 7, 2000. Plants were covered with white polyethylene sheeting from December 20 until December 25, 2000 and from December 29, 2000 until January 5, 2001. Inflorescence counts of 'Autumn Joy' sedum were inadvertently omitted.

In all experiments, an analysis of variance of data was made using the SAS General Linear Model procedure (10). Single degree of freedom orthogonal polynomials were used to test trend responses to NIL, and orthogonal paired comparisons were used to compare each NIL treatment to the natural photoperiod treatment.

Results and Discussion

Average monthly temperatures for Mobile, AL, ranged from 2.3C (4.1F) above normal in February 1999 to 1.1C

Table 1. Average monthly temperatures and departures from normal for Mobile, AL (30.7° north latitude, 88.2° west longitude) from February through June 1999, 2000, and 2001.

	C (F)[z]					
Month	**1999**	**Departure[y]**	**2000**	**Departure**	**2001**	**Departure**
February	14.1 (57.3)	2.3 (4.1)	13.4 (56.2)	1.7 (3.0)	14.4 (58.3)	2.8 (5.1)
March	14.8 (58.6)	–1.1 (–1.9)	17.6 (63.6)	1.7 (3.0)	13.9 (56.9)	–2.0 (–3.6)
April	21.6 (70.8)	1.7 (3.0)	18.2 (64.7)	–1.7 (–3.0)	21.1 (69.6)	–1.0 (–1.8)
May	23.1 (73.6)	–0.5 (–0.9)	24.9 (76.9)	1.3 (2.4)	23.5 (74.5)	0.0 (0.0)
June	26.2 (79.1)	–0.7 (–1.3)	26.4 (79.6)	–0.4 (–8.0)	26.1 (79.1)	–2.4 (–1.3)

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

[y]Departure from normal (30-year average); weather data provided by the National Weather Service, Silver Spring, MD.

(1.9F) below normal in March 1999, from 1.7C (3.0F) above normal in February and March 2000 to 1.7C (3.0F) below normal in April 2000, and from 2.8C (5.1F) above normal in February 2001 to 2C (3.6F) below normal in March 2001 (Table 1). Over the February to June duration of the study, average temperatures were 1.7C (3.0F) and 2.6C (4.7F) above normal in 1999 and 2000, respectively, and 2.6C (4.7F) below normal in 2001.

'*Moonbeam' coreopsis*. Time to flower of 'Moonbeam' coreopsis, a qualitative LDP (2, 4, 7), decreased linearly with increasingly earlier NIL lighting in 1999, 2000, and 2001 (Tables 2–4). Plants exposed to NIL beginning February 1 flowered an average of 15 to 29 (1999), 3 to 21 (2000), and 1 to 11 (2001) days before those receiving NIL beginning February 15, March 1, and March 15, respectively. Plants under all NIL flowered earlier than those under the natural photoperiod, 7 to 36 days earlier in 1999 (Table 2) and 9 to 20 days earlier in 2001 (Table 4). Staggered initiation of NIL coupled with the natural photoperiod resulted in flowering plants in early April and successive crops in peak flower until the cultivar's natural flowering period in May, thus, expanding marketability. Accelerated flowering of 'Moonbeam' coreopsis outdoors under NIL agrees with results of a previous study (8) using other LD herbaceous perennial cultivars.

Flower and flower bud counts of NIL 'Moonbeam' coreopsis were 200 to 244% higher than those of plants under the natural photoperiod in 1999 (Table 2), and flower and flower bud ratings were 73 to 127% (Table 3) and 20 to 60% (Table 4) higher in 2000 and 2001, respectively.

In all three years, plants exposed to NIL were taller and had a greater growth index than plants grown under the natural photoperiod. Increases in height of NIL plants compared to plants under the natural photoperiod ranged from 66 to 85%, 140 to 160%, and 44 to 57% in 1999, 2000, and 2001, respectively. Increases in growth index were similar. Incandescent lamps used for NIL in this study and in most other photoperiod studies (2, 7) are rich in far-red light, the part of the spectrum that promotes stem elongation. Other light sources, including cool-white fluorescent, high-pressure sodium, and metal halide lamps, may be used effectively for NIL of LDPs with less flower stem elongation (6).

While plants exposed to NIL were taller, they were full and considered highly marketable, as reflected in their quality ratings. Quality ratings of plants under NIL were 25 to 43% (1999) and 84 to 126% (2000) higher than those of plants under the natural photoperiod, reflecting plant fullness and higher flower and flower bud counts. Quality ratings in 2001 were similar for plants under NIL and the natural photoperiod, primarily because of a less pronounced increase in flowering under NIL compared to flowering under natural photoperiod than in previous years.

'Early Sunrise' coreopsis. Time to flower of 'Early Sunrise', a qualitative LDP (2, 4), was shortest under NIL when lighting was begun February 1 and increased linearly with increasingly later NIL start dates, from 3 to 12 days in 2000

Table 2. Effects of night-interrupted lighting on selected containerized herbaceous perennials grown outdoors in Mobile, AL (30.7° north latitude, 88.2° west longitude), 1999.

Lighting treatment[z]	**Days to flower[y]**	**Flower and flower bud count**	**Height (cm)**	**Growth index[x] (cm)**	**Quality rating[w]**
			'Moonbeam' coreopsis		
February 1	67*[v]	141*	47.8*	49.7*	4.3*
February 15	82*	137*	51.1*	50.6*	4.0*
March 1	88*	122*	46.6*	45.1*	4.4*
March 15	96*	123*	43.1*	42.8*	4.1*
Natural	103	41	25.9	33.0	3.2
Significance[u]	L***	NS	L*	L***	NS
			'Autumn Joy' stonecrop		
February 1	135*	8*	31.3	31.8	3.4
February 15	137*	8*	38.9	37.8	3.4
March 1	137*	7*	39.1	34.2	3.3
March 15	147*	6*	38.5	33.6	3.3
Natural	173	2	35.4	30.0	3.3
Significance	NS	NS	NS	NS	NS
			'Red Beauty' obedient plant		
February 1	109*	14*	97.4	61.1	3.6
February 15	134*	18*	98.8	58.7	3.6
March 1	140*	16*	91.4	57.5	3.0
March 15	141*	24	98.6	59.3	3.9
Natural	161	26	95.5	56.8	3.2
Significance[u]	L***	L**	NS	NS	NS

[z]Night-interrupted lighting between 10:00 pm and 2:00 am begun on these dates.

[y]Days to flower beginning February 1, 1999.

[x]Growth index = (height + widest width + width perpendicular) ÷ 3.

[w]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 than '3' and larger plant, adequate flower and flower buds; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings.

[v]Means followed by an asterisk significantly different from mean for natural photoperiod treatment, $P = 0.05$; mean separation by orthogonal contrasts (n = 10).

[u]Response to initiation date nonsignificant (NS) or linear (L) at the 0.05 (*), 0.01 (**) or 0.001(***) level; natural treatment not included in analyses.

Table 3. Effects of night-interrupted lighting on selected containerized herbaceous perennials grown outdoors in Mobile, AL (30.7° north latitude, 88.2° west longitude), 2000.

Lighting treatment[z]	Days to flower[y]	Flower and flower bud count[x]	Height (cm)	Growth index[w] (cm)	Quality rating[v]
		'Moonbeam' coreopsis			
February 1	66	3.4*[u]	43.6*	44.7*	4.3*
February 15	69	3.1*	46.5*	45.9*	4.0*
March 1	74	2.7*	44.4*	43.6*	3.7*
March 15	87	2.6*	47.4*	48.1*	3.5*
Natural	—[t]	1.5	18.2	25.5	1.9
Significance[s]	L***	L**	NS	NS	L**
		'Early Sunrise' coreopsis			
February 1	60*	45*	49.8*	43.5	5.0*
February 15	63*	45*	48.8*	45.0*	5.0*
March 1	69*	41*	45.6*	42.3	4.8*
March 15	72*	36*	44.5*	41.4	4.7*
Natural	75	28	38.1	40.6	4.2
Significance	L***	L***	L***	NS	L**
		'Sunray' coreopsis			
February 1	62*	47*	47.7*	43.5*	5.0
February 15	66*	51*	50.7*	47.6*	5.0
March 1	67*	53*	48.8*	45.9*	5.0
March 15	73	47*	51.5*	47.3*	4.6
Natural	75	39	37.6	39.7	4.8
Significance	L***	Q*	NS	L*	L**
		'Blue Queen' salvia			
February 1	40*	22*	31.8*	26.2*	4.7*
February 15	35*	22*	34.0*	29.5*	4.5*
March 1	44	21*	31.7*	29.5*	4.7*
March 15	47	19*	30.0*	27.3	4.5*
Natural	47	12	25.0	24.8	4.0
Significance	L*	NS	NS	Q*	NS

[z]Night-interrupted lighting between 10:00 pm and 2:00 am begun on these dates.

[y]Days to flower beginning February 1, 2000.

[x]Actual counts for all species except 'Moonbeam' coreopsis which was rated on the following scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150, 5 = 200 flowers and flower buds.

[w]Growth index' (height + widest width + width perpendicular) ÷ 3.

[v]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 than '3' and larger plant, adequate flower and flower buds; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings.

[u]Means followed by an asterisk significantly different from mean for natural photoperiod treatment, $P = 0.05$; mean separation by orthogonal contrasts (n = 10). Actual counts for all species except 'Moonbeam' coreopsis which was rated on the following scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds.

[t]Data not collected on plants in the natural treatment.

[s]Response to NIL initiation date nonsignificant (NS), linear (L) or quadratic (Q) at the 0.05 (*), 0.01 (**) or 0.001(***) level; natural treatment not included in analyses.

(Table 3) and from 2 to 7 days in 2001 (Table 4). Plants under all NIL treatments flowered earlier than those under the natural photoperiod, 3 to 15 days earlier in 2000 and 1 to 8 days earlier in 2001. Accelerated flowering of 'Early Sunrise' coreopsis was less pronounced than observed in 'Moonbeam' coreopsis, probably due to the naturally earlier flowering of 'Early Sunrise' coreopsis observed under natural photoperiod. However, earlier flowering of up to 12 days may have the practical benefit of expanding the marketing window into a time period more closely coinciding with peak market demand.

Table 4. Effects of night-interrupted lighting on selected containerized herbaceous perennial grown outdoors in Mobile, AL (30.7° north latitude, 88.2° west longitude), 2001.

Lighting treatment[z]	Days to flower[y]	Flower and flower bud count[x]	Height (cm)	Growth index[w] (cm)	Quality rating[v]
		'Moonbeam' coreopsis			
February 1	80*[u]	2.2*	49.3*	56.6*	3.3
February 15	81*	2.4*	54.6*	63.8*	3.5
March 1	89*	2.3*	53.6*	61.9*	3.4
March 15	91*	1.8*	52.3*	55.0*	3.2
Natural	100	1.5	34.2	39.9	3.1
Significance[t]	L***	NS	NS	Q*	NS
		'Early Sunrise' coreopsis			
February 1	67*	71*	50.1*	46.3*	4.3
February 15	69*	77*	49.0*	45.8*	4.1
March 1	72*	75*	50.5*	44.9*	4.3
March 15	74*	59*	48.4*	42.4*	4.5
Natural	75	47	34.7	36.3	4.4
Significance	L***	Q**	NS	NS	Q*
		'Sunray' coreopsis			
February 1	71*	67	40.4*	41.9*	4.3
February 15	70*	77*	48.2*	43.1*	4.2
March 1	72*	82*	48.3*	43.0*	4.5
March 15	76	75*	46.3*	40.8*	4.3
Natural	78	57	35.4	36.2	4.6
Significance	L*	NS	Q**	NS	NS
		'Autumn Joy' stonecrop			
February 1	131*	—[s]	42.9	37.3	4.1
February 15	132*	—	44.0	37.5	3.7
March 1	138*	—	50.9	42.1	3.9
March 15	146*	—	44.1	35.0*	3.5
Natural	188	—	51.8	43.5	3.6
Significance	L***	—	NS	NS	NS
		'Red Beauty' obedient plant			
February 1	124*[u]	29	109.0	58.9	3.5
February 15	127*	29	112.4	60.8	3.5
March 1	142*	27*	107.1	62.2	3.4
March 15	153*	33	109.7	60.4	3.2
Natural	178	36	105.7	59.6	3.5
Significance[t]	L***	NS	NS	NS	NS
		'Blue Queen' salvia			
February 1	54*	28*	36.7*	29.6*	4.0
February 15	56*	29*	40.8*	32.3*	4.2*
March 1	62	29*	38.1*	31.2*	4.6*
March 15	63	23	33.7*	28.1	3.9
Natural	64	18	26.9	25.1	3.6
Significance	L***	NS	Q*	NS	Q*

[z]Night-interrupted lighting between 10:00 pm and 2:00 am begun on these dates.

[y]Days to flower beginning February 1, 2001.

[x]Actual counts for all species except 'Moonbeam' coreopsis which was rated on the following scale: 1 = 0, 2 = 50, 3 = 100, 4 = 150, and 5 = 200 flowers and flower buds.

[w]Growth index = (height + widest width + width perpendicular) ÷ 3.

[v]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 than '3' and larger plant, adequate flower and flower buds; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings.

[u]Mean followed by an asterisk significantly different from mean for natural photoperiod treatment, $P = 0.05$; mean separation by orthogonal contrasts (n = 10).

[t]Response to NIL initiation date nonsignificant (NS), linear (L) or quadratic (Q) at the 0.05 (*), 0.01 (**) or 0.001 (***) level; natural treatment not included in analyses.

[s]Flower and flower bud counts inadvertently not recorded.

Flower and flower bud counts decreased linearly up to 20% in 2000 as the start of NIL was delayed (Table 3) and changed quadratically in 2001 with the highest counts in plants exposed to NIL beginning February 15 (Table 4). All plants under NIL formed more flowers and flower buds than plants under the natural photoperiod; increases ranged from 29 to 61% in 2000 and from 26 to 64% in 2001.

There were no differences in height or growth index among plants under NIL in either year, except for a linear decrease in height of up to 11% with an increasingly later start of light treatments in 2000. However, plants in all NIL treatments were taller than those under the natural photoperiod at first flower, 17 to 31% taller in 2000 and 39 to 46% taller in 2001. Likewise, growth index of all plants under NIL in 2001 was 17 to 28% greater than that of plants under the natural photoperiod. In 2000, only plants exposed to NIL beginning February 15 had a greater growth index (11% higher) than those under the natural photoperiod.

Quality rating of plants exposed to NIL in 2000 was 12 to 19% greater than that of plants under the natural photoperiod; however, all plants were considered highly marketable having a quality rating of ≥4.5. In 2001 quality ratings of plants under NIL and the natural photoperiod were similarly high.

'Sunray' coreopsis. Results of exposure of 'Sunray' coreopsis, a quantitative LDP (4), to NIL were similar to those with 'Moonbeam' and 'Early Sunrise' coreopsis. Time to flower decreased linearly with increasingly earlier NIL, 4 to 11 days in 2000 and 1 to 5 days in 2001. All plants under NIL flowered earlier than those under the natural photoperiod, except for plants exposed to NIL beginning March 15, 2000 and 2001 (Tables 3 and 4). Flower and flower bud counts, height, and growth index of plants exposed to NIL were greater than those of plants under the natural photoperiod in both years, with the exception of similar flower and flower bud counts for plants exposed to NIL beginning February 1, 2001. Increases in flower and flower bud counts, height and growth index were similar to those reported for the other two coreopsis cultivars. Plant quality was consistently high for all plants, regardless of photoperiod treatment.

'Autumn Joy' sedum. Time to flower in 'Autumn Joy' sedum, a qualitative LDP (11), decreased linearly 1 to 15 days in 2001, but not 1999, with increasingly earlier NIL (Tables 2 and 4). Plants in all NIL treatments flowered earlier than those under the natural photoperiod, 26 to 38 days earlier in 1999 and 42 to 57 days earlier in 2001. Inflorescence counts of plants exposed to NIL were three to four times greater than those of plants under natural photoperiod in 1999. Neither plant height, growth index, nor quality rating was affected by the treatments, and all plants were considered marketable at first flower, although plants were much taller in 2001 than in 1999.

'Red Beauty' obedient plant. Time to flower of 'Red Beauty' obedient plant, a qualitative LDP (2, 4, 5), decreased linearly with increasingly earlier NIL. Plants exposed to NIL beginning February 1 flowered 25 to 32 days earlier in 1999 and 3 to 29 days earlier in 2001 than did plants lighted at later dates (Tables 2 and 4). Inflorescence counts increased linearly with increasingly later NIL start dates, 29 to 71% higher than counts of plants exposed to NIL beginning February 1, 1999. However, inflorescence counts of plants under NIL beginning March 1 or earlier were 38 to 46% lower than those of plants under the natural photoperiod. Inflorescence counts were not reduced by NIL in 2001, except when plants were lighted beginning March 1. As with 'Autumn Joy' sedum, NIL accelerated flowering, but had no effect on plant height, growth index, or quality rating. Plants in all treatments were relatively tall which was largely responsible for most plants having a quality rating of between 3 and 3.5.

'Blue Queen' salvia. Time to flower of 'Blue Queen' salvia, a quantitative LDP (4), decreased linearly with exposure to increasingly earlier NIL, up to 7 and 9 days earlier in 2000 and 2001, respectively (Tables 3 and 4). However, when compared to plants under the natural photoperiod, flowering time decreased only when NIL was begun on February 1 or February 15, 7 to 12 days in 2000 and 8 to 10 days in 2001. Compared to plants under the natural photoperiod, inflorescence counts increased with exposure to all NIL treatments, except a March 15 start in 2001; increases ranged from 58 to 83% in 2000 and from 56 to 61% in 2001. Plants under NIL were 20 to 36% taller than those under the natural photoperiod in 2000 and 25 to 52% taller in 2001; similar increases in growth index also were evident. Quality rating was 13 to 18% higher in plants under NIL in 2000 and 17 to 28% higher in plants exposed to NIL beginning February 15 or March 1, 2001, than in plants under the natural photoperiod. However, the quality of plants in all treatments was good to excellent in both years and plants were considered marketable.

In summary, NIL promoted earlier flowering of all species, but generally was less effective in the naturally earlier flowering species 'Early Sunrise' and 'Sunray' coreopsis and 'Blue Queen' salvia. This promotion of earlier flowering in quantitative and qualitative LDPs agrees with the previously reported earlier flowering of 'Goldsturm' coneflower and 'Coronation Gold' yarrow, both qualitative LDPs (8). In addition to earlier flowering, flower and flower bud counts increased under NIL in all cultivars, except 'Autumn Joy' sedum in 2001 and 'Red Beauty' obedient plant in both years tested. NIL promoted height growth of all cultivars, except 'Autumn Joy' sedum and 'Red Beauty' obedient plant. However, the increased height did not adversely affect plant quality, and in several cases quality rating of plants exposed to NIL was higher than that of plants under the natural photoperiod, probably due to moderate height increases, enhanced floral display or both. Staggered starting dates of NIL outdoors under nursery conditions has the potential to greatly expand the marketing windows of the cultivars used in this study, while requiring minimal resources.

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