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Accelerated Flowering of Herbaceous Perennials Under Nursery Conditions in the Southern United States[1]

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Abstract

A study was conducted to determine the effects of night-interrupted (NI) lighting initiated at different times in late winter on several herbaceous perennials produced outdoors in a southern nursery setting. Treatments were NI lighting beginning February 1, February 15, March 1, March 15, and a natural photoperiod. NI lighting accelerated flowering in 'Goldsturm' coneflower (*Rudbeckia fulgida* Ait. 'Goldsturm') 26–46 days in 1999 and 51–75 days in 2000, and in 'Coronation Gold' yarrow (*Achillea* x 'Coronation Gold') 2–9 days in 1999 and 2–11 days in 2000. Flower and flower bud counts increased 82–100% in 'Coronation Gold' achillea in 1999, 44–51% in 'Butterfly Blue' scabious (*Scabiosa columbaria* L. 'Butterfly Blue') and 100–151% in 'Alaska' shasta daisy (*Leucanthemum* x *superbum* Bergmans ex. J. Ingram 'Alaska') compared to counts of plants under natural photoperiod. With few exceptions, plant height increased under all NI lighting treatments, but in only 'Goldsturm' coneflower did it reduce plant quality. Clump verbena (*Verbena canadensis* L.) was minimally affected by NI lighting, and speedwell (*Veronica spicata* L. 'Sunny Border Blue') was not affected at all.

Index words: night-interrupted lighting, photoperiod, container production.

Species used in this study: 'Coronation Gold' yarrow (*Achillea filipendulina* Lam. x *Achillea clypeolata* Sibth. & Sm. 'Coronation Gold'), 'Goldsturm' coneflower (*Rudbeckia fulgida* Ait. 'Goldsturm'), 'Butterfly Blue' scabious (*Scabiosa columbaria* L. 'Butterfly Blue'), 'Alaska' shasta daisy (*Leucanthemum* x *superbum* Bergmans ex. J. Ingram 'Alaska'), clump verbena (*Verbena canadensis* L.), and 'Sunny Border Blue' speedwell (*Veronica spicata* L. 'Sunny Border Blue').

Significance to the Nursery Industry

Herbaceous perennials can be forced into flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod. Growers in the southern United States may have a similar opportunity by exposing plants to night-interrupted (NI) lighting outdoors from 10 p.m. to 2 a.m. Flowering of 'Goldsturm' coneflower and 'Coronation Gold' yarrow, being qualitative long-day plants, was accelerated by NI lighting 26–75 days and 2–11 days, respectively. In addition to earlier flowering in these species, NI lighting increased flower and flower bud production in 'Coronation Gold' yarrow (up to 100%), 'Butterfly Blue' scabious (44–51%), and 'Alaska' shasta daisy (100–151%). Earlier and enhanced flowering using NI lighting outdoors under nursery conditions in the southern United States has the potential to expand the marketing window and market quality of these and other long-day herbaceous perennials.

Introduction

Herbaceous perennials flower at various times during the growing season. However, these plants 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. Flowering is a complex physiological process controlled by internal and external factors, including exposure to low temperatures and photoperiod (4, 13). Vernalization is a cold temperature treatment that promotes flowering at subsequent higher temperatures (14). Even when vernalization is not required for flowering, many herbaceous perennials benefit from cold exposure by earlier or improved flowering (1, 2, 5). 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-interupted lighting from 10:00 p.m. to 2:00 a.m. generally is recommended to induce flowering of long-day plants (LDPs) (1, 2, 5), including the qualitative long-day plants, *Achillea millefolium* 'Summer Pastels' (19), *Coreopsis verticillata* 'Moonbeam' (7), and *Rudbeckia fulgida* 'Goldsturm' (13). 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 *Phlox paniculata* 'Eva Cullum' (12), *Coreopsis grandiflora* 'Sunray', and *Leucanthemum* x *superbum* 'Snowlady' and other seedlings (2). 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 greenhouse 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 hardiness zone 8. Cool nights and mild days in late winter provide ideal conditions for growth of many herbaceous perennials. Night-interrupted lighting outdoors, providing a minimum of 10 ft-candles at plant height, could provide photo-inductive conditions for flowering of many herbaceous perennials earlier than natural photoperiods. By staggering the initiation of long days, the potential exists to provide successive crops in peak flower from spring to the plants' natural flowering period, thus extending the market period for these plants. In addition, this technique may be beneficial to quantitative LDPs, many of which produce more flowers under LDs than under natural SDs. The objective of our study was to determine the effectiveness of night interrupted lighting initiated on different dates on flowering of selected her-

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baceous perennials grown outdoors in the southeastern United States.

Materials and Methods

Fifty transplants each of *Rudbeckia fulgida* 'Goldsturm' ('Goldsturm' coneflower), *Achillea* x 'Coronation Gold' (yarrow), *Scabiosa columbaria* 'Butterfly Blue' ('Butterfly Blue' scabious), *Leucanthemum* x *superbum* 'Alaska' ('Alaska' shasta daisy), *Verbena canadensis* (clump verbena) and *Veronica spicata* 'Sunny Border Blue' (speedwell) were transplanted on December 18, 1998, from 70-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 Substation, Mobile, AL (USDA hardiness zone 8b), and watered as needed from overhead impact sprinklers. Plans were made 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 year of the study was protection necessary.

A night-interrupted (NI) 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 (PAR) at plant height averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NI lighting area. Ten plants of each species were moved from an adjacent block into the NI lighting block on February 1, February 15, March 1, and March 15, 1999. Ten plants of each species remained as unlighted controls. After the initiation of lighting treatments, pots were spaced so that plant canopies just touched. Spacing varied with species, and increased as plants grew. A black plastic curtain separated plants receiving NI lighting and unlighted control plants to a height of 1.8 m (6 ft) to prevent light leakage in an adjacent area. 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 species in the NI lighting block were randomized as separate experiments.

The date of the first fully-opened flower was recorded. At this time, flower and flower bud number, 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, 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. Only transplants of 'Goldsturm' coneflower and 'Coronation Gold' yarrow achillea were evaluated; these were potted on December 8, 1999. In both experiments, single degree of freedom orthogonal contrasts were used to test responses to NI lighting, and to compare each NI lighting 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 (1.9F) below normal in March 1999, and from 1.7C (3.0F) above normal in February and March 2000 to 1.7C (3.0F) below normal in April 2000 (Table 1). Over the February to June duration of the study, average temperatures were 0.3C (0.6F) and 2.6C (4.7F) above normal in 1999 and 2000, respectively.

'Goldsturm' coneflower. Time to flower decreased quadratically with increasingly earlier NI lighting in both 1999 and 2000 (Tables 2 and 3). Plants exposed to NI lighting beginning February 1 flowered an average of 13, 14, and 20 days before those NI-lighted beginning February 15, March 1, and March 15, 1999, respectively, (Table 2) and 4, 14, and 24 days earlier in 2000 (Table 3). Plants, therefore, flowered in 2%, 15% and 23% less time in 1999 and in 12%, 16% and 20% less time in 2000 from the beginning of NI lighting on Feburary 15, March 1, and March 15, respectively, compared to plants NI lighted beginning February 1. This suggests one or more limiting factors to the photoperiodic response. 'Goldsturm' coneflower is a qualitative LDP with a quantitative flowering-response to cold-temperature treatment (12). In addition, Yuan (16) recommended that to overcome juvenility, plants should have at least 10 nodes before inductive long days are provided. The amount of chilling plants received prior to the initiation of NI lighting treatments in this study is not known. Partially vernalized plugs were received from a northeastern U.S. source in early December. Additionally, there is no direct comparison of chilling hours in a controlled environment and accrued chilling under fluctuating temperatures in an uncontrolled outdoor environment. The most likely explanation for differences in the time from the beginning of NI lighting to flower is that lower temperatures during the early part of the lighted period resulted in a

Table 1. Average monthly temperatures and departures from normal for Mobile, AL from February through June 1999 and 2000.

	C (F)[z]			
Month	**1999**	**Departure[y]**	**2000**	**Departure**
February	14.1 (57.3)	2.3 (4.1)	13.4 (56.2)	1.7 (3.0)
March	14.8 (58.6)	–1.1 (–1.9)	17.6 (63.6)	1.7 (3.1)
April	21.6 (70.8)	1.7 (3.0)	18.2 (64.7)	–1.7 (–3.1)
May	23.1 (73.6)	–0.5 (–0.9)	24.9 (76.9)	1.3 (2.4)
June	26.2 (79.1)	–0.7 (–1.3)	26.4 (79.6)	–0.4 (–0.8)

[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.

Table 2. Effects of night-interrupted lighting on selected containerized herbaceous perennials grown outdoors in USDA zone 8b, 1999.

Lighting treatment[z]	Days to flower[y]	Flower and bud count	Height (cm)	Growth index[x]	Quality rating[w]
			'Goldsturm' coneflower		
February 1	100*[v]	11.0	48.9	38.5	4.1
February 15	113*	12.1	60.3*	40.7*	3.8*
March 1	114*	13.1	62.1*	42.8*	3.9*
March 15	120*	13.9	59.9*	41.2*	3.9*
Natural	146	12.9	50.6	37.8	4.2
Significance[u]	L***Q***	NS	L***Q***	L***Q**	NS
			'Coronation Gold' yarrow		
February 1	53*	6.8*	56.8*	40.9*	3.9
February 15	60	6.2*	49.0*	39.4*	4.2*
March 1	60	5.5	45.8*	38.8*	4.0
March 15	64	4.1	37.0	35.4*	3.9
Natural	64	3.4	35.7	31.6	3.7
Significance[u]	L*	L*	L***	L***	NS
			'Butterfly Blue' scabious		
February 1	39	17.5*	37.6*	31.9*	4.9*
February 15	37	19.3*	32.0*	29.6*	4.9*
March 1	36	18.4*	26.4	25.3	4.8
March 15	39	11.8	23.4	23.9	4.4
Natural	40	12.8	23.4	23.3	4.4
Significance[u]	NS	L*Q*	L***	L***	L**
			'Alaska' shasta daisy		
February 1	81	9.4*	69.4*	52.7*	3.5*
February 15	79	11.8*	75.4*	53.0*	4.1
March 1	82	11.1*	70.9*	53.5*	4.1
March 15	87	10.9*	69.6*	52.7*	4.1
Natural	80	4.7	51.7	41.4	3.9
Significance[u]	NS	NS	NS	NS	L**Q*
			clump verbena		
February 1	31	24.9	36.7*[t]	32.4*	5.0
February 15	32	20.0	33.4	28.3	5.0
March 1	26	22.3	33.3	28.5	5.0
March 15	30	20.1	33.2	27.5	5.0
Natural	29	21.5	31.8	28.3	5.0
Significance[u]	NS	NS	L*Q*	L***	NS

[z]Night-interrupted lighting between 10:00 p.m and 2:00 a.m begun on these dates.

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

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

[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 flowers and flower buds; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants with lower ratings.

[v]Mean followed by an asterisk significantly different from mean for natural treatment, $p = 0.05$; mean separation by orthogonal contrasts.

[u]Regression response nonsignificant (NS), linear (L) or quadratic (Q) at the 0.05 (*), 0.01 (**) or 0.001 (***) level; natural treatment not included in analyses.

[t]Values are the average of the widest width and the width perpendicular to the widest width.

slower rate of growth and development than during the latter part when temperatures were higher. Temperature is a critical factor controlling plant developmental processes, including flowering. As forcing temperature increases, time to flower usually decreases until it reaches a minimum (11). This is supported by Yuan *et al.* (17), who reported the rate to flowering in 'Goldsturm' coneflower increased linearly with temperature over the range of 15–27C (59–81F).

Plants under all NI lighting treatments flowered earlier than those under natural photoperiod, 26–46 days earlier in 1999 (Table 2) and 51–75 days earlier in 2000 (Table 3). Staggered initiation of NI lighting coupled with natural photoperiod resulted in budded plants in late April and successive crops in peak flower from early May until the plant's natural flowering period in July and August, thus, greatly expanding marketability.

Flower and flower bud count were not affected by treatment in either year, except for a 28% increase over plants under natural photoperiod when NI lighting was begun February 1, 2000 (Tables 2 and 3).

In 1999, but not 2000, height and growth index changed quadratically in response to the initiation of NI lighting (Tables 2 and 3). Compared to plants that were lighted beginning February 1, plants lighted at later dates were 23%,

Table 3. **Effects of night-interrupted lighting on selected containerized herbaceous perennials grown outdoors in USDA zone 8b, 2000.**

Lighting treatment[z]	Days to flower[y]	Flower and bud count	Height (cm)	Growth index[x]	Quality rating[w]
			'Goldsturm' coneflower		
February 1	95*[v]	20.9*	58.3*	48.3*	4.3
February 15	99*	18.2	58.4*	48.5*	4.2*
March 1	109*	18.8	59.5*	46.9*	3.9*
March 15	119*	17.4	60.0*	47.8*	3.8*
Natural	170	16.3	39.6	37.0	4.6
Significance[u]	L***Q*	NS	NS	NS	L***
			'Coronation Gold' yarrow		
February 1	60*	12.3	51.0*	40.5*	4.2
February 15	62*	13.2	54.2*	42.5*	4.3
March 1	65*	11.6	52.1*	41.6*	4.2
March 15	69*	9.9	45.6*	40.6*	4.2
Natural	71	11.6	37.3	36.6	4.4
Significance[u]	L***	NS	L*Q*	NS	NS

[z]Night-interrupted lighting between 10:00 p.m and 2:00 a.m begun on these dates.

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

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

[w]Quality rating: 1 = dead; 2 = chlorotic foliage, excessive stem elongation or small plant; 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 flowers and flower buds; 5 = dark green foliage, compact, full plant with more flowers and flower buds than plants in lower ratings.

[v]Mean followed by an asterisk significantly different from mean for natural treatment, $p = 0.05$; mean separation by orthogonal contrasts.

[u]Regression response nonsignificant (NS), linear (L) or quadratic (Q) at the 0.05 (*) or 0.001 (***) level; natural treatment not included in analyses.

27% and 22% taller with a 6%, 11%, and 7% greater growth index. In both years, plants in all lighted treatments, except beginning February 1, 1999, were taller and larger than those under natural photoperiod. The increase in height ranged from 18–23% in 1999 and from 47–52% in 2000. Incandescent lamps, used for NI lighting in this study, 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, can be used effectively for NI lighting of 'Goldsturm' coneflower with less flower stem elongation (18).

Quality ratings in 2000, but not 1999, were affected by timing of NI lighting, with a slight decrease of 2–12% from later initiation of lighting (Tables 2 and 3). In both years, quality ratings were lower than those of plants under natural photoperiod when NI lighting was begun on February 15 or later, 7–9% in 1999 and 9–17% in 2000. Lower quality ratings were due to increased stem elongation under NI lighting.

'Coronation Gold' yarrow. Time to flower decreased linearly in both years with increasingly earlier NI lighting, 4–11 days in 1999 and 2–9 days in 2000 (Tables 2 and 3). Compared to plants under natural photoperiod, plants lit beginning February 1, 1999, flowered 11 days earlier, while plants in all NI lighting treatments flowered 2–11 days earlier in 2000. Under NI lighting accelerated flowering of 'Coronation Gold' yarrow, a qualitative LDP, was less pronounced than observed in 'Goldsturm' coneflower, probably due to the naturally earlier flowering of yarrow. However, earlier flowering of up to 11 days may have the significant practical benefit of expanding the marketing window into a time period more closely coinciding with peak demand.

Flower and flower bud counts increased linearly in 1999, but not 2000, with earlier NI lighting (Tables 2 and 3). Counts from plants initially lighted February 1, February 15, and March 1 were 66%, 51% and 34% higher, respectively, than those from plants lighted beginning March 15. Flower and flower bud counts were 100% and 82% higher in plants receiving NI lighting February 1 and 15, 1999, respectively, compared to plants under a natural photoperiod.

Height and growth index increased linearly in 1999 with earlier NI lighting (Table 2). Plants initially lit February 1, 1999, were 16% (February 15) to 54% (March 15) shorter and had a 4% (February 15) to 16% (March 15) lower growth index than plants lit at later dates. Heights in 2000 changed quadratically in response to NI lighting (Table 3). Heights of plants in all NI lighting treatments, except height in the March 15, 1999, treatment, were greater than those of plants under natural photoperiod. Increases ranged from 28–59% in 1999 and from 22–45% in 2000.

Plant quality in all treatments was considered good to excellent (3.5 quality rating) in both years (Tables 2 and 3). The only significant treatment effect on quality rating was a 14% increase in plants NI-lighted beginning February 15, 1999, compared to plants under natural photoperiod.

'Butterfly Blue' scabious. Time to flower in scabious, a day-neutral plant (2), was not affected by NI lighting treatments (Table 2). However, flower and flower bud counts changed quadratically in response to the initiation of NI lighting. Number of flowers and flower buds were highest in plants lit beginning February 1, and decreased by 10%, 5% and 64% when lighting began on February 1, March 1, and March 15, respectively. Relative to plants under natural photoperiod, counts of plants initially lit on February 1, February 15 and March 1 were 37%, 51% and 44% higher, respectively, but similar to those lit beginning March 15. Long days have been reported as being beneficial to 'Butterfly Blue' scabious (2).

Both height and growth index increased linearly with increasingly earlier lighting (Table 2). Plants NI-lighted beginning February 1 were 6–18% taller and had a growth index 8–33% greater than those initially lit at a later date. When NI lighting began on February 1 and February 15, plants were 61% and 37% taller with a 37% and 27% greater growth index than those of plants under natural photoperiod. Initiation of NI lighting at later days resulted in similar heights and growth index to those of plants under natural photoperiods.

Quality rating increased linearly with earlier lighting, with up to a 15% higher rating when initiated on February 1 (Table 2). Plants lighted beginning February 1 and February 15 had a 11% higher quality rating than those under natural photoperiod. Bailey and Scoggins (3) reported that scabious benefitted from long days and defined a beneficial treatment as one that promoted earlier or more uniform flowering or enhanced plant quality. While earlier flowering was not promoted in our study, flower and flower bud counts and quality rating increased.

'Alaska' shasta daisy. Time to flower in shasta daisy was not affected by NI lighting treatment (Table 2). However, increases in flower and flower bud counts of 100–151% occurred in all lighting treatments relative to those in non-lighted controls. Shasta daisy has been reported as a LDP (10), a qualitative LDP (9, 15), and a quantitative LDP (6). In addition, the effects of photoperiod and cold treatment on flowering of shasta daisy vary by cultivar (6, 8). For example, 'Becky' showed an obligate (qualitative) requirement for long days to completely flower, while 'Snow Cap' and 'Snow Lady' showed a facultative (quantitative) response (8).

The date on which NI lighting was begun had no effect on plant height or growth index of shasta daisy, but, mean plant height and growth index for all NI lighting treatments were greater than those for plants under natural photoperiod (Table 2). Increases in height and growth index ranged from 34–46% and 27–29%, respectively.

Quality rating at first flower changed quadratically in response to the initiation of NI lighting, with a 15% and 10% lower rating for plants lit beginning February 1 compared to those initially lit at a later date and under natural photoperiod, respectively (Table 2).

Clump verbena. NI lighting had no effect on days to flower, flower and flower bud counts, or quality rating in clump verbena, a day-neutral plant (Table 2). Plant width and growth index were greater when NI lighting began on February 1 than with initiation of lighting at a later date or under natural photoperiod. Larger plant size in plants initially lit February 1 probably resulted from exposure to incandescent lamps for a longer period prior to flowering, about 30 days, versus about 15 days or no exposure of plants in other treatments.

'Sunny Border Blue' speedwell. Night-interrupted lighting had no effect on any of the measured variables in speedwell, a day-neutral plant (data not shown).

In summary, NI lighting provided some benefit to all species tested, except clump verbena, that naturally flowered within 30 days of the initiation of the first lighting treatment, and 'Sunny Border Blue' speedwell. NI lighting was most effective in promoting earlier flowering of 'Goldsturm' coneflower and 'Coronation Gold' yarrow, both qualitative LDPs, which could greatly expand the marketing windows of these two cultivars, particularly coneflower which naturally flowers much later than yarrow. In addition to earlier flowering in yarrow, flower and flower bud counts increased with earlier NI lighting in 1999, but not 2000. NI lighting also increased flower and flower bud counts in 'Butterfly Blue' scabious, a quantitative LDP, and 'Alaska' shasta daisy, without affecting time to flower. The most evident potentially detrimental effect from NI lighting was excessive stem elongation that marginally reduced the quality of 'Goldsturm' coneflower in some light treatments. Excessive stem elongation may be controlled using a different light source or a plant growth retardant. In general, quality of plants under NI lighting was similar to or higher than that in plants under natural photoperiod.

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