Effects of Night-Interrupted Lighting on Growth and Flowering Duration of Herbaceous Perennials Grown Under Nursery Conditions in the Southern United States[1]

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Abstract

Staggered starting dates for night-interrupted lighting (NIL) were evaluated for accelerated sequential flowering of herbaceous perennials with different photoperiod requirements outdoors in a southern nursery setting. Plants evaluated were black-eyed Susan (*Rudbeckia fulgida* 'Goldsturm'), an obligate long-day (LD) plant; obedient plant (*Physostegia virginiana* 'Miss Manners'), a facultative LD plant; and Stokes' aster (*Stokesia laevis* 'Peachie's Pick'), a facultative intermediate-day plant. With all species, the dates of first flower and maximum flower number occurred sooner under LDs from incandescent (INC) and fluorescent (FLU) lamps than under natural photoperiod (NP). Mean and maximum flower numbers were greater under NIL than under NP for black-eyed Susan and Stokes' aster but not for obedient plant. Time in flower increased in Stokes' aster, but either decreased or was not affected by NIL for black-eyed Susan and obedient plant. Flowering periods of black-eyed Susan and obedient plant exposed to different NIL timings overlapped extensively while leaving a gap in flowering between plants exposed to NIL and those under NP. This gap in flowering suggests that the intervals between NIL start dates could be longer to lessen the flowering overlap of plants under NIL, and that the interval between the start of the last NIL treatment and the onset of an inductive photoperiod be reduced to maintain sequential peak flowering until the natural flowering period. With Stokes' aster, flowering overlapped for plants in the different NIL timings and under NP, resulting in continuous sequential blooms from first flowering of plants under NIL until the plants' natural flowering period under NP in late May. Flowering periods of Stokes' aster exposed to NIL beginning on different dates overlapped extensively, suggesting that at least one NIL start date could be omitted and the intervals between the start of NIL increased without sacrificing continuous sequential peak flowering. NIL from INC and FLU lamps promoted growth in plant height compared to that of plants under NP, although the increase in plant height was less under FLU lamps.

Index words: flower induction, long-day plant, intermediate-day plant, incandescent lamps, fluorescent lamps, container production.

Species used in this study: black-eyed Susan (*Rudbeckia fulgida* Ait. 'Goldsturm'); obedient plant (*Physostegia virginiana* (L.) Benth. 'Miss Manners'); Stokes' aster (*Stokesia laevis* L'Hér. 'Peachie's Pick').

Significance to the Nursery Industry

Herbaceous perennials can be forced to flower out-of-season under greenhouse conditions by manipulating temperature and photoperiod. By staggering the initiation of night-interrupted lighting (NIL) from 10 p.m. to 2 a.m. under nursery conditions, growers in the southern United States have the potential to provide successive crops of LD and intermediate-day herbaceous perennials in peak bloom from spring until the plants' natural flowering period, thus expanding the marketing window of black-eyed Susan, obedient plant, and Stokes' aster. However, the start of LDs must be scheduled for the individual species and its natural flowering period to avoid excess overlap in peak flowering or a gap between flowering of plants exposed to NIL and those under NP. Black-eyed Susan, and to a lesser extent, obedient plant, will require NIL start date intervals greater than 15 days if NIL is started as early as February 1 and only four start dates are used; the longer interval should allow sequential flowering to occur due to this plant's long flowering period. Peak flowering of Stokes' aster was sequential from first flower of plants under NIL until flowering of plants under NP and it is possible the same response could have been achieved with fewer NIL start dates.

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Introduction

Flowering in plants is controlled by internal and external factors, including exposure to low temperatures (vernalization) and photoperiod (3, 19, 20). Vernalization promotes flowering at subsequent higher temperatures (19), 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 obligate LDP black-eyed Susan (14, 23) and the facultative LDP 'Miss Manners' obedient plant (7). In facultative 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). Less is known about the effects of NIL on facultative intermediate-day plants, such as Stokes' aster, although it was reported that the highest flowering percentage and the fastest time to flower of 'Klaus Jelitto' Stokes aster occurred at photoperiods of 12 and 13 hours, flowering under NIL occurred only after a 15-week cold treatment, and the flowering percentage was never more than 90% (5).

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 (8, 9, 10, 11, 12, 13). Coastal states in the South, primarily in USDA Plant Hardiness Zones 8 and 9, experience cool nights and mild days in late winter that provide conducive 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 'Red Beauty' obedient plant was accelerated by 20 to 54 days (9), and flowering of black-eyed Susan was accelerated by 26 to 46 days in 1999 and 51 to 75 days in 2000 compared to plants grown under a natural photoperiod (NP) (8). However, black-eyed Susan grown under NIL was 18 to 23% (1999) and 48 to 52% (2000) taller than plants under NP at anthesis. Conventional NIL uses incandescent (INC) lamps with a spectral output that is rich in far red wavelengths. Light with a high proportion of far red (700–800 nm) has been shown to increase internode elongation in many plants while light with more red wavelengths (600–700 nm) than far red has less effect on internode elongation (15, 21). Blue light (400–500 nm) independently inhibits extension growth (17). The light source used for NIL outdoors in many previous studies was INC lamps, and plants were taller at first flower than those under natural photoperiods (8, 9, 10, 11, 12, 13). Fluorescent (FLU) lamps are rich in red and/or blue light and low in far red light and may be a viable substitute for INC lamps in NIL, although FLU lamps have delayed flowering of some crops compared to INC lamps (18).

NIL promoted earlier flowering of numerous other LD herbaceous perennials under nursery conditions in previous studies (8, 9, 10, 11, 12, 13); however neither the duration of flowering nor peak flowering was reported, and it is unknown whether staggered NIL start dates in February and March would provide sequential flowering until the plants' natural flowering period. The objective of this study was to determine the effects of NIL begun on different dates on the growth and flowering characteristics of three herbaceous perennials with different flowering requirements. In addition, the effects of two light sources, FLU lamps and the conventional INC lamps, on growth and flowering were compared.

Materials and Methods

'Goldsturm' black-eyed Susan and 'Peachie's Pick' Stokes' aster were transplanted on October 19, 2010, from 72-cell flats (James Greenhouses, Colbert, GA) into 3.8 liter (#1) containers of 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, Everris NA, Dublin, OH), 3.6 kg (6 lb) dolomitic limestone, 1.2 kg (2 lb) gypsum, and 0.9 kg (1.5 lb) Micromax (Everris NA). Plugs of obedient plant from 72-cell flats were transplanted on December 16, 2010, using the same amended substrate and containers. 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 hand-watered as needed. The lowest temperature during the study was –5.5C (22F) so covering of plants for winter protection was not needed.

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 photosynthesis system (LI-COR Biosciences, Lincoln, NE) with a quantum sensor, averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NIL area. An adjacent growing area was constructed similarly using 13-watt fluorescent (FLU) lamps that have an equivalent output in the visible spectrum to 60-watt INC lamps. These lamps delivered proportionately more red than far red light compared to INC, having a red:far red ratio of between 6.8 and 8.8, in contrast to between 0.7 and 1.0 for the INC lamps (6, 22). Curtains made from of woven ground cloth doubled and 1.8 m (6 ft) tall separated plants in the two light treatments, which were 5.5 m (18 ft) apart, and the NP, and were far enough from all plants to provide no shading. Space limitations prevented the replication of the lighting treatments. Ten plants each of black-eyed Susan and Stokes' aster and six plants of obedient plant were moved from an adjacent non-lighted block into the INC NIL block on February 1, February 15, March 1, and March 15; in addition the same numbers of plants of each species were placed in the FLU-lighted block on February 1, 2011. On February 1, 2011, when the first groups of plants were transferred to NIL, black-eyed Susan was in the rosette stage, covered 50 to 90% of the exposed substrate surface, had extensive root development at the root ball surface, and averaged 3.3 cm (1.3 in) tall and 15 cm (5.9 in) wide. At this time, obedient plant was also in the rosette stage and averaged 3.8 cm (1.5 in) tall and 8.1 cm (3.2 in) wide but foliage only covered about 20% of the exposed substrate surface, and roots were just reaching the root ball surface. Stokes' aster, still in the rosette stage, covered 50 to 75% of the exposed substrate surface, had extensive root development at the root ball surface, and averaged 6.8 cm (2.7 in) tall and 18.7 cm (7.4 in) wide on February 1, 2011. Pots were spaced so that plant canopies did not overlap. Spacing varied among cultivars and increased as plants grew. Mean monthly temperatures from the onset of NIL until most plants had flowered were 11.7C (53.1F) in February, 17.2C (63.0F) in March, 21.2C (70.2F) in April, 23.6C (74.4F) in May, and 28.9C (84.0F) in June. Mean monthly temperatures did not depart from normal more than 1.4C (2.5F), except in June [2.9C (3.6F) departure] (AWIS Weather Services, Auburn, AL).

The date of first open flower (inflorescence) was recorded when ray flowers on black-eyed Susan and Stokes' aster were fully reflexed, and when the upper and lower petals of the first open flower on obedient plant were maximally separated. The number of days to first open flower was from February 1, 2011. At first flower, plant height from the substrate surface to the uppermost plant part was measured. Weeks in flower were counts of all weeks when at least one flower was open. The weeks were often not consecutive. Mean flower number was an average of flower counts in weeks when at least one flower was open. The number of days from February 1, 2011, to the date of maximum flower number was counted. In the event of a tie in consecutive weeks, the date of the first occurrence was used.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). A completely randomized design was used, and plant cultivars were treated as separate experiments. Where residual plots and a significant COVTEST statement with the HOMOGENEITY option indicated heterogeneous vari-

Table 1. **The effects of night-interrupted lighting (NIL) using incandescent lamps with four start dates and fluorescent lamps with one start date on growth and flowering of three herbaceous perennials in a nursery setting in 2011.**

Treatment[z]	Days to first open flower[y]	Weeks in flower[x]	Mean flower number[w]	Maximum flower number	Days to maximum flower number[v]	Plant height (cm)
			Rudbeckia fulgida 'Goldsturm'			
Natural	161	8	11	25	190	16.4
FLU 2/1	88ns*[u]	7ns	26ns*	46ns*	115ns*	57.2b*
INC 2/1	89*	7	26*	48*	115*	68.5a*
INC 2/15	90*	7	21*	45*	117*	68.1*
INC 3/1	106*	5*	22*	45*	123*	65.9*
INC 3/15	118*	5*	16*	34*	133*	55.6*
Significance[t]	L***	L***	L***	L***	L***	L***
			Physostegia virginiana 'Miss Manners'			
Natural	137	10	9	29	160	31.2
FLU 2/1	95a*	7ns	9ns	25[s]	107a*	68.5b*
INC 2/1	87b*	6*	15*	35	101b*	84.5a*
INC 2/15	79*	7	11	25	99*	87.7*
INC 3/1	101*	6*	9	27	112*	88.3*
INC 3/15	109*	7	8	25	121*	82.7*
Significance	L***	NS	L***	NS	L***	NS
			Stokesia laevis 'Peachie's Pick'			
Natural	111	3	12	20	122	55.0
FLU 2/1	90ns*	4ns*	19ns*	32b*	107ns*	58.5b*
INC 2/1	91*	5*	21*	41a*	109*	63.4a*
INC 2/15	92*	5*	17*	36*	110*	64.6*
INC 3/1	101*	5*	16	34*	116*	67.3*
INC 3/15	108*	4*	17*	35*	121	67.9*
Significance	L***	Q**	L*	L*	L***	L**

[z]Plants exposed to NIL between 10:00 p.m. and 2:00 a.m. beginning on the date listed in 2011; NIL using fluorescent (FLU) or incandescent (INC) lamps; plants in the natural treatment were not exposed to NIL.

[y]Beginning February 1, 2011.

[x]Counts of weeks where at least one flower was open.

[w]An average of flower counts in weeks where at least one flower was open.

[v]From February 1, 2011, to the date of maximum flower number.

[u]Least squares means comparisons of all NIL treatments (*) to the natural photoperiod using Dunnett's test. Paired comparison of FLU to INC (lower case letters in columns) beginning on February 1, 2011, using Bonferroni's test. ns = not significant. All tests at $\alpha = 0.05$.

[t]Significant linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

[s]Because the overall model (max flower number = treatments) was not significant, we did not perform a means comparison.

ance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Where residual plots indicated right-skewed residuals for counted responses, data were analyzed using the negative binomial distribution with a log link. Least squares means for the natural photoperiod treatments were compared to all NIL treatments using Dunnett's test. A paired comparison of fluorescent and incandescent treatments starting on February 1, 2011, were made using Bonferroni's test. Linear and quadratic trends over NIL dates were tested using orthogonal polynomials in CONTRAST statements. All significances were at $\alpha = 0.05$.

Results and Discussion

Black-eyed Susan. Days from February 1 to first flower in black-eyed Susan decreased linearly up to 29 days as the start of NIL was initiated progressively earlier, from March 15 to February 1, and all plants exposed to NIL flowered 43 to 72 days before those under NP (Table 1). This shifting the onset of flowering by starting long days sooner is similar to that previously reported for black-eyed Susan grown outdoors under NIL (7, 10, 12) and could greatly expand the marketing windows of this cultivar, which typically doesn't flower until July in the lower South. In addition to earlier flowering, weeks in flower, mean flower number, and maximum flower number increased linearly with progressively earlier NIL start dates, while days to maximum flower number decreased linearly. Cooler temperatures associated with earlier flowering probably contributed to the longer period of plants in flower and possibly higher mean and maximum flower numbers, while warmer temperatures associated with later start dates of NIL probably shortened the time to maximum flower number (16, 22). Mean and maximum flower numbers of plants in all NIL treatments were higher and days to maximum flower number lower than those of plants under NP. However, plants under NP were in flower for a longer period than plants exposed to NIL beginning March 1 and March 15, but not earlier. Beginning NIL at 15-day intervals did not result in corresponding 15-day intervals in days to first flower or days to maximum flower number, most likely due to the lack of environmental control outdoors, particularly of temperature (16, 22). Instead, differences in days to first flower of plants between adjacent NIL start dates were 1 (February 1 and 15), 16 (February 15 and March 1), and 12 days (March 1 and 15), while differences in days to maximum flower number were 2, 6, and 10 days, respectively. These reduced intervals in first and peak flowering coupled with the greatly accelerated flowering under NIL and the naturally late flowering of black-eyed Susan resulted in much overlap in flowering of plants in the NIL treatments and a large gap in peak flowering between the NIL and NP groups (Fig. 1). These results suggest that the intervals between NIL start dates could be longer or additional start dates after March 15 need to be included to maintain sequential peak flowering from May until August. There were no visual treatment effects on flower size, although flower size was not measured on any of the species.

Plant height at first flower decreased linearly as the start of NIL was delayed (Table 1). However, plants exposed to NIL from INC lamps were still 239 to 318% taller than plants under NP at first flower. Similar increases in height were reported when black-eyed Susan and other species were exposed to NIL outdoors from INC lamps (8, 9, 11, 13), although plants under NP were much shorter in this study. Plants exposed to NIL from FLU lamps were about 20% shorter than those under NIL from INC lamps without affecting flowering attributes. However, plants under FLU NIL were still over 248% taller than plants under NP, indicating little practical benefit of changing to FLU lamps, a source with a higher ratio of red:far red light than INC, just to promote more compact plants in black-eyed Susan.

Obedient plant. Similar to black-eyed Susan, days to first flower in obedient plant decreased linearly up to 30 days as the start of NIL was initiated progressively earlier, and all plants exposed to NIL flowered 28 to 58 days before those under NP (Table 1). This shifting the onset of flowering of obedient plant outdoors under NIL is similar to the 20 to 54 days shift in earlier flowering in 'Red Beauty' obedient plant grown under NIL outdoors (9) and reinforces the potential benefits of this system for facultative LDPs. Likewise, days to maximum flower number decreased linearly at progressively earlier NIL start dates, while mean flower number increased. Also, all plants exposed to NIL reached maximum flower number sooner than plants exposed to NP, while only plants exposed to NIL beginning February 1 had mean flower numbers greater than plants under NP. Weeks in flower and maximum flower number were not affected by NIL start date. Also similar to black-eyed Susan, flowering periods of plants exposed to NIL overlapped extensively followed by a gap before peak flowering of plants under NP (Fig. 2), although the gap was much shorter than with black-eyed Susan due to the naturally earlier flowering of obedient plant. These results suggest that the intervals between the start of NIL could be increased while still maintaining extensive overlapping of flowering of plants exposed to NIL, thus reducing or eliminating the gap in flowering between NIL and NP plants. In contrast to black-eyed Susan, obedient plant exposed to NIL from FLU reached first flower and maximum flower 8 and 6 days, respectively, before plants exposed to NIL from INC lamps, but like black-eyed Susan, plants were about 20% shorter at first flower, which agrees with previous research (15, 17, 22). However, plants exposed to FLU NIL were still 120% taller than NP controls, while plants exposed to INC NIL were 165 to 183% taller, without being affected by NIL start date.

Stokes' aster. Similar to black-eyed Susan and obedient plant, days to first flower in Stokes' aster decreased linearly up to 17 days as the start of NIL was initiated progressively earlier, and all plants exposed to NIL flowered 3 to 20 days before those under NP (Table 1). While NIL promoted earlier flowering of this facultative intermediate-day plant, the response was less than with either black-eyed Susan, an obligate LDP, or obedient plant, a facultative LDP, probably due to the highest flowering percentage of Stokes' aster being under 12 and 13 hour photoperiods (5). Inadequate cold treatment may also have been a factor in delayed flowering, as 'Klaus Jelitto' Stokes' aster flowered under INC NIL only after a 15-week cold treatment, and the percentage was never higher than 90% (5). However, plants in all treatments flowered during this study. In addition to earlier flowering, mean and maximum flower numbers increased linearly with

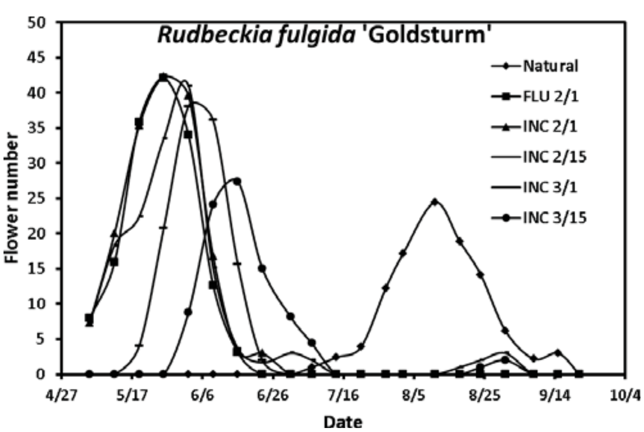

Fig. 1. **Flower numbers for black-eyed Susan in response to night-interrupted lighting (NIL) from incandescent lamps with four start dates and fluorescent lamps with one start date in 2011.**

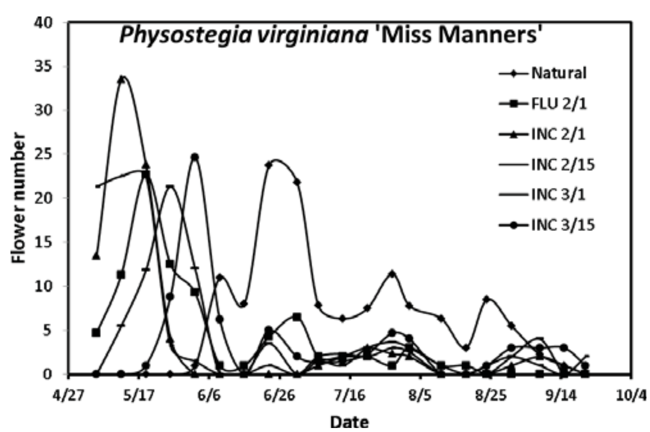

Fig. 2. **Flower numbers for obedient plant in response to night-interrupted lighting (NIL) from incandescent lamps with four start dates and fluorescent lamps with one start date in 2011.**

progressively earlier NIL start dates, while days to maximum flower number decreased linearly. Mean and maximum flower numbers of plants in all NIL treatments were higher and days to maximum flower number lower, except with a March 15 start date, than those of plants under NP. In addition, plants under NIL were in flower for 1 to 2 weeks longer than plants exposed to NP. Similar to black-eyed Susan and obedient plant, flowering periods of plants exposed to NIL overlapped extensively (Fig. 3), suggesting that at least one NIL start date could be omitted and the intervals between the start of NIL increased without sacrificing continuous sequential peak flowering. In contrast to both black-eyed Susan and obedient plant, peak flowering of Stokes' aster was sequentially continuous from early May until the plant's natural flowering period under NP in late May. This response may in part be due to NIL being less effective in promoting earlier flowering of Stokes' aster, possibly because it is a facultative intermediate-day plant for flowering and requires 15 weeks of cold to flower under NIL (5). Days to first and maximum flower numbers, weeks in flower, and mean flower number were similar for plants exposed to NIL from FLU and INC lamps, while flowering was reduced by 22% and height by 8% with NIL from FLU. Plant height increased linearly with progressively later NIL start dates, and plants were 15 to 23% taller than those under NP, while plants under FLU were only 6% taller.

In summary, results of this study to determine the effects of NIL begun on different dates on the growth and flowering characteristics of three herbaceous perennials with different flowering requirements indicate beneficial flowering effects on obligate LD (black-eyed Susan), facultative LD (obedient plant), and facultative intermediate-day (Stoke's aster) plants. With all species time to first and maximum flower was accelerated under LDs from INC and FLU lamps, mean and maximum flower numbers were greater under NIL than under NP, except with obedient plant, and time in flower increased (Stoke's aster), decreased or was not affected by NIL. Flowering periods of black-eyed Susan and obedient plant exposed to NIL overlapped extensively while leaving a gap in flowering between plants exposed to NIL and those under NP, suggesting that the intervals between NIL start dates could be longer to maintain peak flowering until the plants' natural flowering period. Flowering of Stokes' aster was sequentially continuous from first flowering of plants under NIL until the plant's natural flowering period under NP in late May with no gap. NIL from INC and FLU lamps increased plant height compared to that of plants under NP, a trend previously noted with many herbaceous perennials exposed to NIL from INC lamps (15, 18, 21), although the increase was less under FLU lamps.

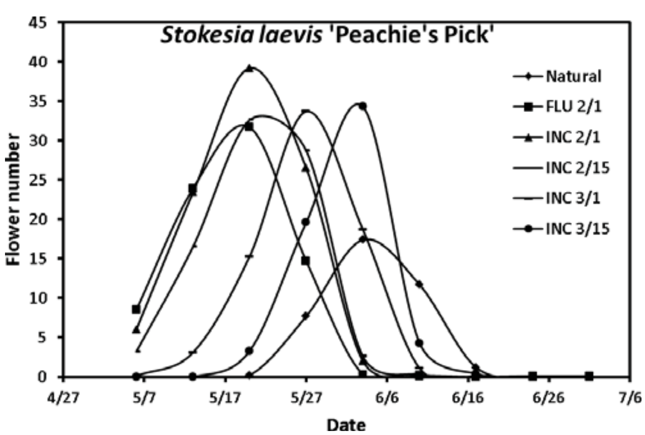

Fig. 3. Flower numbers for Stokes' aster in response to night-interrupted lighting (NIL) from incandescent lamps with four start dates and fluorescent lamps with one start date in 2011.

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