Bulking Duration Affects Growth and Flowering of Herbaceous Perennials Grown Under Nursery Conditions and Forced Into Flower Under Night-Interrupted Lighting Outdoors in the Southern United States[1]

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Abstract

The effects of bulking duration on growth and flowering of 'Goldsturm' black-eyed Susan (*Rudbeckia fulgida* Ait. 'Goldsturm') and 'Moonbeam' coreopsis (*Coreopsis verticillata* L. 'Moonbeam') forced into flower under nursery conditions were evaluated as part of a system for the accelerated production of herbaceous perennials requiring long days to flower. Bulking duration treatments were established by a factorialization of potting date (September 24, October 13, December 2, and December 14, 2009) and night-interrupted lighting (NIL) start date (February 1, February 22, and March 15, 2010). Leaf counts of black-eyed Susan at the beginning of NIL increased linearly with progressively longer bulking durations based on potting date and NIL start date, although the effect was more pronounced when compared across potting dates. Based on leaf counts, black-eyed Susan potted in December were still in the juvenile phase when NIL was begun on February 1, 2010. Stem counts of black-eyed Susan at first flower followed a similar pattern as leaf counts. Black-eyed Susan given NIL flowered 40 to 59 days before plants under natural photoperiod (NP). Flower plus flower bud counts of black-eyed Susan at first flower increased linearly with increasing bulking duration based on potting date: by 325, 268, and 243% when NIL was begun on February 1, February 22, and March 15, respectively. Flower counts also increased linearly approximately 46% with increasing bulking duration based on NIL start dates, but only when plants were potted in December. At first flower, plant height of black-eyed Susan given NIL increased linearly as bulking duration increased based on potting date, but did not differ when trended across the NIL start dates. Days to flower of coreopsis decreased with increasing bulking duration, while stem counts increased with bulking duration, and the number of marketable plants was greater when plants were repotted on the three earliest dates compared to those bulked the shortest duration. Effects of bulking duration on flower plus flower bud counts and height of coreopsis were inconsistent.

Index words: vegetative period, flower induction, long-day plant, container production, nursery production.

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

Significance to the Nursery Industry

Herbaceous perennials are frequently grown in a vegetative state (bulking) to increase root and canopy size, and to possibly enhance flowering prior to being forced into flower. Information to support the benefits of bulking is common but largely anecdotal. This study evaluated bulking durations established by varying potting dates and the start of night-interrupted lighting (NIL) on two herbaceous perennials grown outdoors under nursery conditions. 'Goldsturm' black-eyed Susan benefitted from longer bulking durations by allowing plants to grow out of juvenility prior to being forced into flower. In addition, longer bulking increased stem and flower counts several fold. Increased bulking was also beneficial to 'Moonbeam' coreopsis. Days to flower decreased with increasing bulking duration, a response not previously reported in scientific literature, while stem counts increased with bulking duration. Based on potting date, fewer coreopsis bulked the shortest duration were marketable compared to those bulked for longer periods. However, the effects of bulking duration on flower plus flower bud counts and height of coreopsis were inconsistent. These results support early fall potting of black-eyed Susan and coreopsis plugs when plants are grown outdoors under nursery conditions in the southern United States, whether forced into flower beginning as early as February or allowed to flower naturally.

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Introduction

Bulking, defined as the vegetative growth period before a herbaceous perennial is forced into flower, such as by photo-inductive photoperiods, can be used to ensure a plant has passed through the juvenile phase and is mature enough to flower (14, 22) which can vary with cultivar (22); to build the plant to a size more suitable for forcing in a particular container size (13, 15, 17); or to build the root system, allowing the plant to become well established (5, 11). The increase in the size of the root system is believed to result in a greater number of shoots of sufficient developmental size to respond to photo-inductive photoperiods, possibly resulting in more flowers and/or flowering shoots (11, 14, 17). The above citations are largely anecdotal and, in general, bulking recommendations fall into one or more of the following categories: 1) bulking is recommended, but no start time or duration is given (16); 2) bulking duration is given in weeks, months, or, in one case, years (13, 15); 3) plugs or liners are recommended to be transplanted into final containers in a specific month or season (14, 17); and 4) bulking is recommended to allow a plant to outgrow the juvenile phase (14, 22).

The length of the bulking period may vary with cultivar, but is often determined by the initial transplant size of the plant and the finished plant size for a chosen container size. For example, a 72-cell plug transplanted into a 1 liter (1 qt) container may require less bulking time than a 72-cell transplanted into a 3.8 liter (1 gal) pot. Perennials are forced by the industry in containers ranging from 10 cm (4 in) to 3.8 liter (1 gal) and larger in size. Pilon (12) reported that several perennials, including *Aquilegia* spp. (columbine), *Dianthus gratianopolitanus* Vill. (cheddar pink) and *Phlox subulata* L. (creeping phlox), must be potted in early fall to sufficiently bulk them in the final container to have adequate foliage for plants to be marketable. Bulking of achillea before a cold treatment was not required, but desirable to fill a 12.7 cm (5 in) or larger container (10), while bulking of anemone for 12 to 15 weeks was recommended to increase root mass (5). Hamrick (7) recommended that if growers choose to force plants, such as 'Moonbeam' coreopsis and 'Goldsturm' black-eyed Susan, into flower for spring sale, plants must be bulked under short days so that roots can fully develop throughout the pot prior to flower induction.

Flowering is controlled by internal and external factors, including exposure to low temperatures (vernalization) and photoperiod (3, 19, 21). Vernalization promotes flowering at subsequent higher temperatures (20), and even when vernalization is not required for flowering, many herbaceous perennials benefit from cold exposure by earlier or improved flowering (1, 2, 4). 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 (6) and 'Goldsturm' black-eyed Susan (18, 23). 'Moonbeam' coreopsis (7) has an obligate requirement for long photoperiods to flower, ≥14 hr photoperiod or a 4 hr NIL, while 'Goldsturm' black-eyed Susan is an obligate LD, cold-beneficial plant (23). With at least 9 weeks of cold, 'Goldsturm' black-eyed Susan flowered faster and the flowering percentage, number of flowers, and plant height increased compared to plants not receiving a cold treatment. Without a cold treatment, the critical photoperiod is approximately 14 hr, whereas 'Goldsturm' black-eyed Susan that has been vernalized has a critical photoperiod of about 13 hr and will flower 2 to 3 weeks earlier. In addition, 'Goldsturm' black-eyed Susan, but not 'Moonbeam' coreopsis, has a juvenile period during which plants will not flower until mature; this period is present until plants have formed at least 10 leaves (23).

While the above cited photoperiod research was conducted in greenhouses or in growth chambers under climate controlled conditions, similar responses were reported in LDPs grown outdoors under nursery conditions in the southeastern United States where environment control was lacking (8, 9). 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' black-eyed Susan was accelerated by 26 to 46 days in 1999 and by 51 to 75 days in 2000 when compared to plants grown under a natural photoperiod (NP) (8). Night-interrupted lighting accelerated time to flower and increased flower counts of 'Moonbeam' coreopsis by 7 to 36 days and 20 to 244%, respectively (9). However, 'Goldsturm' black-eyed Susan grown under NIL was 18 to 23% (1999) and 48 to 52% (2000) taller than plants under natural photoperiods (NP) at anthesis and plant quality rating was lower in both years. Similarly, 'Moonbeam' coreopsis under NIL was up to 155% taller than plants under NP.

In previously published studies on forcing herbaceous perennials into flower under nursery conditions in the southern United States, plugs or rooted cuttings were transplanted into finished containers between November and January prior to exposing plants to photo-inductive conditions as early as February (8, 9). The effects of bulking duration on growth and flowering of herbaceous perennials under greenhouse and nursery conditions is largely anecdotal, and to our knowledge, there is no published research on how bulking duration affects growth and flowering of herbaceous perennials forced into flower under nursery conditions, the objective of this study with 'Goldsturm' black-eyed Susan and 'Moonbeam' coreopsis.

Materials and Methods

Seedlings of 'Goldsturm' black-eyed Susan and unbranched rooted cuttings of 'Moonbeam' coreopsis in 125-cell flats (Ball Horticultural Co., West Chicago, IL) were transplanted on September 24, October 14, December 2, and December 14, 2009, into 2.8 liter (#1 trade) pots containing a 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). At potting on September 24, October 14, December 2, and December 15, 2009, 'Goldsturm' black-eyed Susan had leaf counts of 4, 8, 6, and 6 (Table 1) and 'Moonbeam' coreopsis had heights of 10.2, 7.2, 11.3, and 7.6 cm (4.0, 2.8, 4.4, and 3.0 in), respectively. Plants were grown pot-to-pot outdoors in full sun through the winter under NP at the Ornamental Horticulture Research Center, Mobile, AL (USDA cold hardiness zone 8b; 30.7°N, 88.2°W), and were watered as needed from overhead impact sprinklers. Pots were re-spaced as plants grew so that plant canopies did not overlap. Plants were covered with white polyethylene from January 4–11, 2010, due to predicted temperatures below –6.7C (20F).

A night-interrupted lighting block was established outdoors in the nursery area to provide a minimum of 10 foot-candles of light from 10:00 p.m. to 2:00 a.m. Sixty watt incandescent lamps were spaced 1.3 m (4 ft) on center within rows and 1.5 m (5 ft) between rows. Lamps were placed 1.2 m (4 ft) above ground level and 1.1 m (3.5 ft) or less above plants. Photosynthetically-active radiation at plant height, as measured with a LI-COR LI-6400 steady-state porometer (LI-COR Biosciences, Lincoln, NE), averaged 1.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ over the NIL area. Space limitations prevented the replication of the lighting set-up. On February 1, February 22, and March 15, 2010, 10 plants of each cultivar from each potting date were moved under NIL; 10 uniform plants of each cultivar from each potting date remained as unlighted controls. Because coreopsis from the September potting had elongated shoots with remnants of flower buds and because elongated shoots on plants from the October potting died from low temperature exposure, all coreopsis from these two potting dates were pruned to ~2.5 cm (1 in) in height on February 1, 2010, at the start of the first

Table 1. Effects of bulking duration based on potting date and night-interrupted lighting (NIL) start date on growth and flowering of *Rudbeckia fulgida* 'Goldsturm' in a nursery setting in the southeastern United States.[z]

	NIL[y]				
	None (natural)	February 1	February 22	March 15	
Potting dates[x]	**Leaf counts[w]**				**Sign.[v]**
September 24	4c[u]	59*[t]	80*	114*	L***
October 13	8a	47*	69*	83*	L***
December 2	6b	6	13*	32*	L***
December 14	6ab	6	10*	24*	L***
Significance		L***	L***	L***	
Potting dates	**Flower and bud counts[s]**				**Sign.**
September 24	50	68	81*	79*	NS
October 13	37	44	49*	50*	NS
December 2	47	27*	40	39	L*
December 14	41	16*	22*	23*	L**
Significance	NS	L***	L***	L***	
Potting dates	**Stem counts**				**Sign.**
September 24	16	17	20	21	L**
October 13	11	7*	10	12	L***
December 2	9	3*	5*	7	L***
December 14	7	1*	2*	3*	L***
Significance	L***	L***	L***	L***	
Potting dates	**Height (cm)**				**Sign.**
September 24	47.3	62.9*	65.3*	65.1*	NS
October 13	46.7	66.0*	68.0*	68.6*	NS
December 2	54.2	58.1	60.0	59.8	NS
December 14	54.9	52.2	56.3	57.3	NS
Significance	L***	L***	L***	L***	

[z]The potting date by NIL start date interactions were significant for all responses at $\alpha = 0.05$.

[y]NIL was started on February 1, February 22, or March 15, 2010. Natural = natural photoperiods.

[x]Plants were potted into final containers on September 24, October 13, December 2, or December 14, 2009.

[w]Leaf counts were recorded at potting.

[v]Non-significant (NS) or significant (Sign.) linear (L) trends using orthogonal contrasts at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). Trend analysis over NIL start dates did not include the natural photoperiod.

[u]Least squares means comparisons among potting dates (column) for the natural photoperiod using Bonferroni's test at $\alpha = 0.05$.

[t]Least squares means comparisons of the natural photoperiod to the NIL start dates (rows) using Dunnett's test at $\alpha = 0.05$ (*). Leaf counts were recorded at each NIL start date.

[s]Flower and bud counts, stem counts, and plant heights were recorded at first open flower.

NIL treatment. Coreopsis from the third and fourth potting dates had been pruned prior to shipment and most had not developed any elongated shoots by the start of the first NIL treatment, so plants were not pruned. Cultivars were treated as separate experiments. 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, and was far enough from all plants to provide no shading.

Treatments consisted of a factorial arrangement of different bulking durations based on the number of days between potting (September 24, October 14, December 2, and December 15, 2009) and the beginning of NIL (February 1, February 22, and March 15, 2010), plus plants potted on the four dates and held under NP (Table 2). Leaves of 'Goldsturm' black-eyed Susan were counted and height of 'Moonbeam' coreopsis was measured at potting and at the beginning of each NIL. The dates of the first fully-opened flower (inflorescence) were recorded; first flower was considered when ray flowers on the first inflorescence were fully reflexed. At first flower, flower plus flower bud counts, stem number at the pot rim, and plant height from the substrate surface to the uppermost plant part were recorded. In addition, coreopsis were assessed as being either marketable or unmarketable using a rating that considered flower plus flower bud coverage of the canopy, canopy fullness and symmetry, stem density, and foliar color.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). A completely randomized experimental design was used with a factorial treatment design of potting date and

Table 2 Bulking days for each combination of potting date and night-interrupted lighting (NIL) start date.

Potting dates[y]	NIL start dates[z] February 1	February 22	March 15
September 24	130[x]	151	172
October 13	111	132	153
December 2	61	82	103
December 14	49	70	91

[z]NIL was started on February 1, February 22, or March 15, 2010.

[y]Plants were potted into final containers on September 24, October 13, December 2, or December 14, 2009.

[x]Bulking days were counted from the potting dates to the NIL start dates.

NIL start date. Because the potting dates were not equally spaced, they were coded as number of days from the first potting date, September 24, which was assigned 0 days. Where residual plots and a significant COVTEST statement with the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity on either the main effects or the interaction depending on which choice minimized the Akaike's Information Criterion (AIC) value. For leaf counts of 'Goldsturm' coneflower and plant height of 'Moonbeam' coreopsis recorded at the beginning of each NIL, linear and quadratic trends over potting dates at each NIL start date, and trends over NIL dates for each potting date were tested using orthogonal polynomials in CONTRAST statements. Least squares means comparisons for plants potted on the four dates and placed under the NP were compared using Bonferroni's test. For responses recorded at first open flower, linear and quadratic trends over potting dates at each NIL start date, and trends over NIL dates for each potting date were tested using orthogonal polynomials in CONTRAST statements. Least squares means comparisons of the NP to all NIL dates were made using Dunnett's test. Marketability ratings (plants rated marketable / total observations per treatment) of 'Moonbeam' coreopsis were analyzed using the binary probability distribution, but results are presented as percent marketable plants. Linear, quadratic, and cubic trends over potting dates were tested using orthogonal polynomials in CONTRAST statements, but were not significant. Therefore, paired comparisons of treatment marketability counts were made using CONTRAST statements. All significances were at $\alpha = 0.05$.

Results and Discussion

Average monthly temperatures in Mobile, AL, ranged from 2.2C (4.0F) above normal in September 2009 to near normal in December 2009, while temperatures in January and February 2010 were well below normal and those March through June were well above normal (Table 3). The first freeze did not occur until December 6, 2009, and there were only six freeze events the entire month, as opposed to 15 in January with a low of –10.6C (13F) and 14 in February 2010 (data not shown).

'Goldsturm' black-eyed Susan. Leaf counts of 'Goldsturm' black-eyed Susan at potting ranged from an average of four to eight with the fewest leaves present on plants potted September 24 and the most on plants potted October 13, which were similar in number to those on plants potted December 2 and 14 (Tables 1 and 2). Based on these leaf counts, all plants were still in the juvenile phase when potted (23).

There was an interaction between potting date and NIL start date for leaf counts, flower and bud counts, stem counts, and plant height of black-eyed Susan. Based on potting date and the start of NIL, leaf counts of black-eyed Susan increased linearly with progressively longer bulking durations, although the effect was more pronounced across potting dates, probably because potting dates spanned 81 days and included warm fall growing conditions, while NIL start dates spanned only 43 days during a cooler part of the year (Tables 1 and 3). On February 1, the first NIL start date, leaf counts on plants potted the previous September 24 were 9-fold greater than those of plants potted on December 14. In addition, plants potted in December had fewer than 10 leaves, so plants were still in the juvenile phase, which would make them unresponsive to photo-inductive conditions. Even with the latter two NIL start dates of February 22 and March 15, leaf counts were 8-fold and almost 5-fold, respectively, greater in plants potted on the earliest date compared to the latest date. In contrast to the first NIL start date, by the second NIL start date all plants had developed more than 10 leaves and were mature enough to respond to photo-inductive conditions. The linear increases in leaf counts in response to progressively later NIL start dates ranged from 93% with plants potted September 24 to 300% with plants potted December 14. The higher percentage with the later potting dates reflects the low leaf counts of these plants at the first NIL start date; the total leaf counts on March 15 were still much lower in plants potted later.

Only the NIL start date main effect was significant for days to flower. Days to first flower of black-eyed Susan changed quadratically in response to the start of NIL and were not affected by potting date (Table 4). Plants exposed to NIL beginning either February 22 or March 15 flowered about 18 days quicker than those exposed beginning February 1. This difference is most likely due to the higher temperatures following the start of the last two NIL treatments (6, 11, 23). For example, 'Goldsturm' black-eyed Susan forced at 21C (70F) took 11 to 12 weeks to reach flower, while plants

Table 3. Average monthly temperatures and departures from normal for Mobile, AL from September 2009 through June 2010.

Month	Temperature[z] C (F)	Departure[y] C (F)
September	27.7 (81.9)	2.2 (4.0)
October	22.1 (71.7)	1.8 (3.3)
November	15.7 (60.2)	0.3 (0.5)
December	11.7 (53.0)	–0.1 (–0.1)
January	8.7 (47.7)	–1.2 (–2.1)
February	8.9 (48.0)	–2.9 (–5.2)
March	14.1 (57.3)	1.7 (3.1)
April	21.3 (70.4)	1.4 (2.6)
May	26.8 (80.2)	3.2 (5.7)
June	30.2 (86.3)	3.3 (5.9)

[z]Temperatures measured 1.5 m (5 ft) above ground at the Ornamental Horticulture Research Center, Mobile, AL.

[y]Departures from normal (30-year average); temperature data provided by AWIS Weather Services, Inc., Auburn, AL.

Table 4. **Effects of bulking duration based on night-interrupted lighting (NIL) start date, averaged across potting date, on days to flower of *Rudbeckia fulgida* 'Goldsturm' in a nursery setting in the southeastern United States.[z]**

NIL start dates	Bulking (days)	Date of first flower	Days to first open flower[y]
None (natural photoperiod)	—	June 30	149
February 1, 2010	88[x]	May 21	109*[w]
February 22, 2010	109	May 23	90*
March 15, 2010	130	June 15	92*
Sign.[v]			Q***

[z]Only the bulking duration based on NIL start date main effect was significant at α = 0.05.

[y]Counted from the start of NIL. Days to flower for plants under natural photoperiod based upon February 1, 2010 start date. Flowers were considered open when ray flowers on the first inflorescence were fully reflexed.

[x]Average number of bulking days over potting start dates.

[w]Least squares means comparisons of the natural photoperiod to the NIL start dates using Dunnett's test at α = 0.05 (*).

[v]Significant (Sign.) quadratic (Q) trend using orthogonal contrasts at α = 0.001 (***). Trend analysis over NIL start dates did not include the natural photoperiod.

grown at 15C (59F) flowered in 14 to 15 weeks (23). Plants in all NIL treatments flowered 40 to 59 days before those exposed to NP, which is consistent with a previous study in which 'Goldsturm' black-eyed Susan was exposed to NIL under nursery conditions (8).

Flower plus flower bud counts of black-eyed Susan increased linearly with increasing bulking duration based on potting date: by 325, 268, and 244% when NIL was begun on February 1, February 22, and March 15, respectively (Table 1). Flower plus flower bud counts also increased linearly ~46% with increasing bulking duration based on NIL start dates, but only when plants were potted in December. As with leaf counts, the effect on flower plus flower bud counts was less pronounced than when bulking duration was based on potting date, most likely due to a smaller range in bulking durations and lower temperatures during the bulking period. Flower plus flower bud counts on black-eyed Susan exposed to NP were not affected by potting date.

Stem counts of black-eyed Susan at first flower followed a similar pattern as leaf counts and flower counts in response to bulking duration (Table 1). Based on potting date and the start of NIL, stem counts increased linearly with progressively longer bulking durations, although the effect was more pronounced with staggered potting dates. Stem counts increased by 13, 18, and 18 shoots when bulking durations were determined by potting dates and NIL was begun on February 1, February 22, and March 15, respectively. When bulking duration was determined by NIL start dates, increases in shoot counts ranged from two to seven with the latest (December 14) and the earliest (September 24) potting dates. Stem counts likewise increased linearly with increasing bulking durations of plants exposed to NP, indicating a beneficial effect of bulking on black-eyed Susan whether forcing plants into flower under NIL or allowing them to flower naturally.

Height of black-eyed Susan increased linearly by 21, 16, and 14% as bulking duration increased based on potting date, but not NIL start date, when NIL was begun on February 1, February 22, and March 15, respectively (Table 1). In contrast, height of plants exposed to NP decreased linearly by up to 15% as bulking duration increased based on potting date. Height of plants potted on September 24 and October 13 and exposed to NIL were taller than corresponding plants under NP, while those potted later and exposed to NIL were similar in height to plants under NP. Previous studies with black-eyed Susan and other herbaceous perennials grown under nursery conditions have shown that NIL from incandescent lamps, a source rich in far-red light, often promoted shoot elongation (8, 9). The lack of height difference between plants potted in December and NP controls may reflect the smaller plant size, fewer leaves present and being in the juvenile phase (all plants on February 1 and some plants on February 21) when plants were first exposed to NIL.

'Moonbeam' coreopsis. Because plants transplanted in September and October were pruned on February 1, but plants repotted in December were not, we have not reported any statistics for plant height at the beginning of each NIL. On the three NIL start dates (February 1, February 22, and March 15), plants transplanted in September and October averaged less than 5 cm (2 in) in height, while those repotted in December averaged 6.0 cm (2.4 in) to 10.1 cm (4.0 in), depending upon treatment (data not shown). 'Moonbeam' coreopsis does not have a juvenile phase, so a minimum plant size is not required for plants to flower in response to photo-inductive conditions (6, 11).

There was an interaction between potting date and NIL start date for days to flower, flower plus flower bud counts, and stem counts in coreopsis. Days to flower of 'Moonbeam' coreopsis decreased linearly with progressively longer bulking durations based on both potting date and the start of NIL, although the effect was more pronounced with staggered NIL start dates (Table 5), probably because ambient temperatures were rapidly increasing during late winter and early spring which would greatly accelerate floral development (6, 11, 23). Decreases in days to flower with increasing bulking duration ranged from 12 to 15 days when based on potting date, and from 18 to 23 days when based on NIL start date. Likewise, days to flower of plants exposed to NP decreased linearly as bulking duration increased. However, all plants forced into flower under NIL flowered earlier than NP controls, except those potted September 24 and forced beginning February 1. Decreases in days to flower, relative to plants under NP, ranged from 14 to 19 days, 20 to 38 days, and 24 to 38 days when NIL was begun on February 1, February 22, and March 15, respectively. Anecdotal literature recommends bulking

Table 5. Effects of bulking duration based on potting date and night-interrupted lighting (NIL) start date on growth and flowering of *Coreopsis verticillata* 'Moonbeam' in a nursery setting in the southeastern United States.[z]

	NIL[y]				
	None (natural)	February 1	February 22	March 15	
Potting dates[x]	Days to flower[w]				Sign.[v]
September 24	83	82	63*[u]	59*	L***
October 13	109	90*	71*	72*	L***
December 2	104	90*	68*	70*	L***
December 14	112	94*	78*	74*	L***
Sign.	L***	L***	L**	L**	
Potting date	**Flower and bud counts**				**Sign.**
September 24	35	178*	170*	155*	NS
October 13	131	187	201*	212*	NS
December 2	115	198*	166	180	NS
December 14	110	156	127	130	NS
Sign.	Q*	NS	Q*	Q***	
Potting date	**Stem counts**				**Sign.**
September 24	19	33*	39*	27	NS
October 13	16	16	18	15	NS
December 2	10	9	10	9	NS
December 14	8	6	6	7	NS
Sign.	L***	L***	L***	L***	

[z]The potting date by NIL start date interactions were significant for all responses at $\alpha = 0.05$.

[y]NIL was started on February 1, February 22, or March 15, 2010. Natural = natural photoperiods.

[x]Plants were potted into final containers on September 24, October 13, December 2, or December 14, 2009.

[w]Date of first open flower, flower and bud counts, and stem counts were recorded at first open flower. Flowers were considered open when ray flowers on the first inflorescence were fully reflexed.

[v]Non-significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal contrasts at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***). Trend analysis over NIL start dates did not include the natural photoperiod.

[u]Least squares means comparisons of the natural photoperiod to the NIL start dates (rows) using Dunnett's test at $\alpha = 0.05$ (*).

to overcome juvenility, promote plant establishment, and build plant size (5, 11, 13, 14, 15, 17, 22). To our knowledge, this is the first report in scientific literature of reduced days to flower in response to increased bulking duration, a response we observed with 'Moonbeam' coreopsis, but not 'Goldsturm' black-eyed Susan.

Flower plus flower bud counts of coreopsis changed quadratically in response to increased bulking duration, based on potting date, when NIL was begun on February 22 or March 15 or when plants were grown under NP, but not when plants were forced under NIL beginning February 1 or based on staggered NIL start dates (Table 5). When NIL was begun on February 22 or March 15, plants bulked the shortest duration had the fewest flowers and flower buds at first flower. In contrast, plants grown under NP and bulked the longest had the fewest flowers and flower buds at first flower. We are uncertain why the effect of bulking duration differed so dramatically under NP.

Stem counts of coreopsis at first flower increased linearly with progressively longer bulking durations based on potting date, but not staggered NIL start dates. Stem counts increased by 11, 13, 18, and 18 stems when bulking durations were determined by potting dates and plants were grown under NP or NIL was begun on February 1, February 22, and March 15, respectively (Table 5). These results support the anecdotal observations reporting increased shoot production of sufficient size to possibly increase flowering (11, 14, 17). However, flower plus flower bud counts at first flower were only increased with increasing bulking durations when NIL was begun on February 22 and March 15, compared to no effect when begun on February 1. We did not track flowering beyond first flower. The lack of effect of increased bulking duration based on staggered NIL start dates on stem counts was likely due to the low temperatures plants were exposed to between February 1 and March 15 and the concomitant limited shoot growth that occurred.

Both potting date and NIL start date affected height of coreopsis, but there was no interaction between the two. Plant height changed quadratically in response to increasing bulking durations based on potting date (Table 6). The shortest plants at first flower, those potted on September 24, 2009, were also the plants that flowered first (Table 5). Plants potted on December 14, 2009, were intermediate in height, while those potted on the remaining two dates were the tallest. Plant height decreased linearly in response to increasing bulking durations based on NIL start date, but by less than 4 cm (1.6 in), and all plants exposed to NIL, regardless of bulking duration, were taller than plants grown under NP. These

Table 6. **Effects of bulking duration based on potting dates averaged over NIL start dates and based on NIL start dates averaged over potting dates on plant height and marketability of *Coreopsis verticillata* 'Moonbeam' in a nursery setting in the southeastern United States.**

Potting dates	Bulking (days)	Height (cm)[z]	Marketability rating (%)[y]
Sep. 24, 2009	151[x]	38.0	77
Oct. 13, 2009	132	50.0	80
Dec. 2, 2009	82	51.9	70
Dec. 14, 2009	70	46.6	36
Sign.[w]		Q***	Q**
NIL start dates	**Bulking (days)**	**Height (cm)**	
Natural photoperiod	—	36.7	
Feb. 1, 2010	88[v]	48.5*[u]	
Feb. 22, 2010	109	48.9*	
Mar. 15, 2010	130	52.2*	
Sign.		L*	

[z]Only the potting date and the NIL start date main effects were significant at α = 0.05. Recorded at first open flower.

[y]Only the potting date main effect was significant at α = 0.05. Plants were rated marketable or unmarketable at first open flower by considering flower and flower bud coverage of the canopy, canopy fullness and symmetry, stem density, and foliar color. Percent marketable plants were calculated from the number of plants rated marketable / total observations.

[x]Average number of bulking days over NIL start dates.

[w]Significant (Sign.) linear (L) or quadratic (Q) trend using orthogonal contrasts at α = 0.05 (*), 0.01 (**), or 0.001 (***).

[v]Average number of bulking days over potting dates.

[u]Least squares means comparisons of the natural photoperiod to the NIL start dates using Dunnett's test at α = 0.05 (*).

increased heights of plants exposed to NIL from incandescent lamps are consistent with results with 'Goldsturm' black-eyed Susan in this study and with 'Moonbeam' coreopsis in a previous study under nursery conditions (9).

Marketability rating of coreopsis was affected by bulking duration based on potting date, but not NIL start date (Table 6). Plants potted on the first three potting dates had similar marketability ratings of 77, 80, and 70%, while those potted on December 14 had a lower rating of only 36%. The lower rating of plants bulked for the shortest duration reflected the plants' greatly reduced stem counts that made them appear leggy and less symmetrical.

'Goldsturm' black-eyed Susan clearly benefitted from longer bulking durations based on potting dates and NIL start dates. With longer bulking durations, plants had matured by the first NIL start date so as to be responsive to photo-inductive stimuli, as opposed to plants potted on the last potting date which were still in the juvenile phase, one of the primary reasons for bulking (14, 22). Both stem counts and flower counts increased several fold as bulking duration increased which agrees with anecdotal literature (11, 14, 17), while height of plants exposed to NIL also increased with bulking duration based on potting date. This latter response may be due to larger root systems when black-eyed Susan are bulked longer (5, 11). Bulking was also beneficial to 'Moonbeam' coreopsis. Days to flower decreased with increasing bulking duration, a response not previously reported in scientific literature, while stem counts increased with bulking duration. Based on potting date, fewer plants bulked the shortest duration were marketable compared to similar numbers for those bulked for longer durations. The effects of bulking duration on flower plus flower bud counts and height of coreopsis were inconsistent. As in a previous study under nursery conditions (9), plants exposed to NIL from incandescent lamps were taller than those grown under NP. These results support early fall potting of black-eyed Susan and coreopsis plugs when plants are grown outdoors under nursery conditions in the southern United States, whether forced into flower beginning as early as February or allowed to flower naturally.

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