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Strategies to Force Flowering of six Herbaceous Garden Perennials

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Additional index words. ***Platycodon grandiflorus* 'Mariesii', *Campanula persicifolia, Coreopsis* 'Moonbeam', *Lysimachia clethroides, Phlox* 'Fairy's Petticoat', *Echinops* 'Taplow Blue', forcing, photoperiod**

Summary. A renewed interest in perennial garden plants occurred during the 1980s. The need for more information on how to force the plants for flower-show exhibition prompted this research. Experiments were designed that combined the effects of cold storage, daylength, and greenhouse temperature on the development of perennials. The six species and cultivars studied were categorized by the interaction of cold and daylength on their growth and flowering strategy.

Perennial plants persist for more than two growing seasons when environmental conditions are favorable in their native or cultivated habitat. They are more permanent than annual and biennial plants, which die at the end of their first or second growing season. The term "perennials," as used in the horticultural trade, commonly refers to non-woody plants whose roots survive winter conditions while their stems often die to the ground.

A renewed interest in perennial plants and gardens occurred during the 1980s. Gertrude Jekyll, the doyenne of the English herbaceous border, regained popularity. Boxloads of cut perennials were exported from Holland and unpacked in the New York City flower markets to help satisfy the demand for floral arrangements that convey the "English garden look" (Ferguson, 1987). The "New American Garden," planted at the National Arboretum in 1986, is "held together with large sweeps of perennials" and is "a prototype of an emerging garden style" (Cathey, 1988). An expanded perennial plant industry developed to produce the plants that these bold, romantic landscapes require.

This research was prompted after an attempt to force perennial garden plants for a Long Island, N. Y., winter flower show in 1983. Few species responded to the traditional astilbe schedule used. It became apparent that more information was needed on how to force herbaceous perennial plants.

Experiments were designed that combined the effects of cold storage, daylength, and greenhouse temperature on the development of perennials. More than 24 species or cultivars that flower at different seasons and possess exceptional display characteristics, such as flower form, color, fragrance, and longevity, were selected for experimental forcing. The results with the following six species and cultivars are used to summarize the findings: *Platycodon grandiflorus* 'Mariesii', balloon flower; *Campanula persicifolia*, peach-leaved bellflower; *Coreopsis* 'Moonbeam'; *Lysimachia clethroides*, gooseneck loosestrife; *Phlox* 'Fairy's Petticoat'; and *Echinops* 'Taplow Blue', globe-thistle.

Out-of-season forcing of garden perennials is a study in its infancy. Only a handful have had their life cycles described previously and have been successfully forced. *Dendranthema grandiflora* (syn. *(Chrysanthemum morifolium)*, the florist mum, might well be the case study. An herbaceous perennial from the Orient (Bailey, 1941), *D. grandiflora* is a short-day plant that "can be brought into flower almost at will" (Laurie, 1930).

Chrysanthemum x *superbum* 'Marconi', shasta daisy, varies in its photoperiod and vernalization requirements for flowering (Shedron and Weiler, 1982). Some vegetatively propagated clones require cold treatment and/or long photoperiods for flowering. Other clones have a quantitative (additive) response to cold and/or long photoperiods. The longer the cold treatment and/or photoperiod, the greater the promotion of flowering. Still, some clones flower regardless of cold treatment or photoperiod.

Gypsophila paniculata 'Bristol Fairy', perennial baby's breath, is a long-day plant (Shillo and Halevy, 1982) that may require exposure to low temperature to be released from dormancy (Doi, 1984). Clonal variation of the critical daylength exists (Kusey et al., 1981).

Flower bud dormancy of herbaceous peony hybrids, *Paeonia officinalis,* is broken after 4 weeks at 6C. However, increasing the storage time at 6C to 6 weeks or reducing the cold temperature to just above freezing for 4 weeks increases the number of shoots (Byrne, 1988). Greenhouse forcing time, 48 to 52 days, appears to be unaffected by photoperiod.

Liatris spicata 'Gloriosa', gay feather, a cormous perennial plant, requires a minimum of 8 weeks at 3 to 5C for flower induction, release from dormancy, and floral stalk elongation (Waithaka, 1983). The rate of plant emergence, shoot growth, and percentage of flowering increases with increasing durations of cold.

Astilbe x *arendsii*, like peonies and *Liatris*, requires cold treatment for growth and flowering. Here, different cultivars respond differently to

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chilling times (Beattie, 1983). *A.* x *arendsii* 'Fanal' and *A.* x *arendsii* 'Red Sentinel' flower when chilled for 6 weeks. Increased inflorescence number, height, and weight occur when the cold period increases from 6 to 12 weeks.

The vernalization requirement of *Aquilegia* **x** *hybrida,* columbine, also varies among cultivars. Ten weeks at 4.5C is required to induce 100% flowering of 'McKana's Giant', while only 4 weeks at 4.5C is required to induce flowering in 'Fairyland' (Shedron and Weiler, 1982).

Aurinia saxatilis, basket-of-gold, requires 12 weeks of 4. 5C cold treatment to induce 100% flowering. Visible flower buds form quickly after the optimum 12 weeks of cold (Shedron and Weiler, 1982).

Materials and methods

One-year-old, bare-root, field-grown nursery plants of *Platycodon grandiflorus* 'Mariesii', *Coreopsis* 'Moonbeam', and *Echinops* 'Taplow Blue'; seed-propagated transplants of *Campanula persicifolia;* and clonal garden divisions of *Lysimachia clethroides* and *Phlox* 'Fairy's Petticoat' were used for study. Before the experiment began, spent inflorescences of single-stemmed *Lysimachia* and *Phlox* divisions were removed; however, foliated stems were not cut back. *C. persicifolia* plants were potted into 10-cm plastic pots on 29 Aug. 1986. *P. grandiflorus* 'Mariesii', *Coreopsis* 'Moonbeam', *L. clethroides, Phlox* 'Fairy's Petticoat', and *Echinops* 'Taplow Blue' were potted into 15-cm plastic pots on 18 and 25 Sept. and 29 and 27 Aug. 1986, respectively.

The soil mix consisted of 1 pasteurized silty clay loam : 1 sphagnum peat : 1 perlite (by volume). It was amended with 84 g 8.7% P superphosphate, 84 g dolomitic limestone, and 28 g 10N-4.4P–8.3K fertilizer in a 35-liter mix. Plants were established in a 15.5C night, 18.3C day greenhouse under an 8-h daylength. They were irrigated with a 150 ppm 20N-4.4P–16.6K elevated micronutrient fertilizer solution. Standard cultural and pest management practices were followed.

Potted plants were cold-treated at 4.5C in walk-in refrigerators. Species with evergreen basal foliage, *Campanula persicifolia, Coreopsis* 'Moonbeam', and *Echinops* 'Taplow Blue', were lighted with 2 to 4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ incandescent light from 8:00 AM to 4:00 PM to retain foliage during cold storage.

An 8-h photoperiod was created daily with blackcloth cover from 4:30 PM to 8:30 **AM.** A 16-h photoperiod was created daily with blackcloth cover from 4:30 PM to 8:30 AM combined with ≈ 4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ incandescent light from 8 AM until 12:00 midnight. Plants grown under a 24-h photoperiod were not covered with blackcloth, and they received continuous incandescent light at ≈ 4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ incandescent light.

For each treatment, replicates were placed at random in a single block and grown in the greenhouse. Screening studies of many species under several vernalization and photoperiod treatments were feasible using this single-block design. Quantitative growth and developmental results are reported as means and standard deviations. Comparisons among treatments were made with t test procedures.

Studies began 27 Oct. 1986. Species with no evergreen basal foliage were cut back to the soil line. Species with evergreen basal foliage were not cut back. All plants were drenched with the fungicide "Ban-rot" and separated into three groups of 33 individuals. Group 1 received no cold treatment. Groups 2 and 3 were refrigerated at 4.5C for 6 and 12 weeks, respectively. Each group was divided into three subgroups of 11 individuals, which were cut back to the soil line and placed under three different photoperiods: 8, 16, and 24 h (after removal from cold treatment for Groups 2 and 3) in a 15.5C night and 18.3C day greenhouse.

Results and discussion

Crown dormancy of *Platycodon grandiflorus* 'Mariesii' was broken after 6 weeks of cold storage (Table 1). No growth emerged from the crown without a cold treatment. Increased length of the cold treatment from 6 to 12 weeks accelerated the onset of crown growth by an average of 15 days. The length of cold treatment did not influence the rate of inflorescence development once visible growth had begun. The first flower opened 11 to 13 weeks after the onset of growth in a 15. 5C greenhouse. It was difficult to ascertain from these studies if chilling is required for flower induction. Flowering of *P. grandflorus* 'Mariesii' was day-neutral. All plants that received a cold treatment flowered with about the same forcing time, regardless of the photoperiod. Plants grew tallest after extended cold storage and/or under 24-h daylength. *P. grandiflorus* 'Mariesii' stems were weak and required staking.

The minimum time required to treat and force *P. grandiflorus'Mariesii'* for out-of-season flowering was ≈5 months (6 weeks cold storage to break dormancy, 4 weeks to activate growth, and 9 weeks at 15 .5C night temperature for stems to grow and flowers to

Table 1. *Growtb and flowering of* Platycodon *grandiflorus 'Maviesii' after vernalization and photoperiod treatments. Treatment n = 11.*

Storage (weeks) at 4.5C	Photoperiod (h) 8	16	24
	Percent survival		
0	82	82	91
6	100	73	73
12	91	82	73
	Percent of survived plants emerged (n = no. plants emerged)		
0	0	0	0
6	100 (11)	100 (8)	100 (8)
12	100 (10)	100 (9)	100 (8)
	Days in greenhouse to stem emergence (P ≤ 0.0001)		
0	---	---	---
6	28 ± 9 a	21 ± 6 a	25 ± 8 a
12	10 ± 3 b	9 ± 4 b	12 ± 4 b
	Percent of emerged plants flowering (n = no. plants flowered)		
0	---	---	---
6	100 (11)	100 (8)	100 (8)
12	100 (10)	100 (9)	100 (8)
	Days in greenhouse from emergence to visible flower bud (P = 0.03)		
0	---	---	---
6	39 ± 3	35 ± 9	37 ± 5
12	43 ± 4	37 ± 6	39 ± 5
	Days in greenhouse from visible flower bud to first bloom (P = 0.0002)		
0	---	---	---
6	29 ± 3 ab	26 ± 5 b	27 ± 4 b
12	33 ± 4 a	34 ± 3 a	30 ± 4 ab
	Total days in greenhouse from emergence to flowering		
0	---	---	---
6	96 ± 9	82 ± 6	89 ± 13
12	86 ± 6	80 ± 9	81 ± 8
	Plant height (cm) (P = 0.002)		
0	---	---	---
6	53 ± 11 ab	47 ± 10 b	60 ± 12 ab
12	63.9 ± 9 a	66 ± 8 a	65 ± 12 a

open). Lower greenhouse temperatures increased the forcing time.

If forcing begins on 1 Oct., September-dug, field-grown plants could flower around 1 Mar. Earlier flowering is achieved by beginning the treatments earlier, but ≈5 months before the desired date of bloom. Later flowering is possible by extending the preforming cold treatment. Such treatments would be especially useful to promote stem elongation for cut-flower or large potted-plant culture.

Campanula persicifolia required vernalization for inflorescence development (Table 2). No plants that received a 6-week or shorter cold treatment produced reproductive growth, while 40% to 54% of plants that received a 12-week cold treatment flowered within 49 to 53 days (i.e., 7 to 8 weeks). Foliar growth occurred on all plants in all treatments, suggesting that *C. persicifolia* does not require cold treatment to break dormancy. Because flower bud initiation and development occurred at the same rate within all photoperiod groups of those plants that received a 12-week cold treatment, *C. persicifolia* is a day-neutral plant. Heights of plants grown beneath 16- and 24-h photoperiods were significantly taller than those plants grown beneath an 8-h photoperiod. Because the evergreen foliage rosettes are subject to fungal attack during refrigeration, often leading to death, it is necessary to light plants with incandescent lamps for 8 h/day and provide fungicide treatments during refrigeration.

Forced out-of-season, *C. persicifolia* could blossom in ≈5 months (12 weeks of cold storage at 4.5C and 8 weeks of growth in a 15.5C night-temperature greenhouse). Spring-sown seeds produce plants that can flower around the following 1 Mar. if cold-stored beginning 1 'Oct. and greenhouse-forced beginning 1 Jan. Long daylengths encourage stem elongation, and are therefore beneficial for cut-flower production.

Coreopsis 'Moonbeam' is a long-day plant. Flower development only occurred on plants grown at 16- and 24-h photoperiods (Table 3). Vegetative growth emerged on all plants grown at an 8-h photoperiod; however. it remained short (1 to 10 cm) and never flowered. Increased length of photoperiod (24 h) had little effect on the acceleration of flower development. Under long-day conditions, plants within all temperature treatments grew and flowered, indicating that *Coreopsis* 'Moonbeam' had no cold requirement, either for vernalization or to break rhizome dormancy. Tallest plants of 'Moonbeam' were those that were cold-treated and grown under a 24-h photoperiod.

When forced in a 15.5C night temperature greenhouse under a 24-h photoperiod, *Coreopsis* 'Moonbeam' could bloom in ≈9 weeks. September-dug, field-grown plants placed in cold storage and brought into the greenhouse on 25 Dec. could flower around 1 Mar. Later flowering is possible by keeping plants in cold storage or growing at 8-h photoperiods before forcing. Earlier flowering is achieved by starting the schedule sooner.

Lysimachia clethroides required a period of cold to break rhizome dormancy (Table 4). The percent of rhizomes that grew, and the rate at which they emerged from dormancy, accelerated with increased length of cold treatment. Some plants emerged from dormancy without cold; however, to achieve 100% emergence from dormancy in 18 to 19 days, a maximum 12-week cold treatment is required. Growth among the replicates was more uniform after a 12-week cold treatment. This suggests that *L. clethroides* has a quantitative (additive) response to cold.

Inflorescence development only occurred on plants grown at 16- and 24-h photoperiods, suggesting that *L. clethroides* is a long-day plant. Vegetative growth emerged on plants grown under an 8-h photoperiod; however, it remained as a vegetative rosette. Early stages of flower development occurred significantly faster at a 24-h photoperiod than at a 16-h photoperiod in the 0- and 6-week cold treatments. Increased length of cold treatment accelerated early stages of flower development, and the 12-week cold treatment probably had overshadowed the acceleration of flower development produced by a 24-h photoperiod. It is difficult to ascertain from these studies if cold is required for flower induction, as well as for breaking rhizome dormancy. A 24-h photoperiod influences growth in *L. clethroides*. In addition to its acceleration of early stages of flower

Table 2. ***Growth and flowering of* Campanula persicifolia *after vernalization and photoperiod treatments. Treatment n = 11.***

Storage (weeks) at 4.5C	Photoperiod (h) 8	16	24
	Percent survival		
0	---[z]	---[z]	---[z]
6	---[z]	---[z]	---[z]
12	91	91	100
	Percent of survived plants flowering (n = no. plants flowered)		
0	0	0	0
6	0	0	0
12	40 (4)	50 (5)	54 (6)
	Days in greenhouse to visible flower bud (P = 0.53)		
0	---	---	---
6	---	---	---
12	16 ± 7 a	16 ± 3 a	20 ± 8 a
	Days in greenhouse from visible flower bud to first bloom (P = 0.35)		
0	---	---	---
6	---	---	---
12	37+1 a	33+2 a	34+6 a
	Total days in greenhouse to first bloom		
0	---	---	---
6	---	---	---
12	53 ± 6	49 ± 2	53 ±9
	Plant height (cm) (P = 0.08)		
0	---	---	---
6	---	---	---
12	60+5 a	85+15 a	86+23 a

[z]*Data not taken.*

Table 3. ***Growtb and flowering of Coreopsis 'Moonbeam' after vernalization and photoperiod treatments.*[z] *Treatment n = 11.***

Storage (weeks) at 4.5C	Photoperiod (h) 8	16	24
	Percent flowering		
0	0	100	100
6	0	100	100
12	0	100	100
	Days in greenhouse to visible flower bud (P < 0.0001)		
0	---	34 ± 0 a	28 ± 0 b
6	---	34 ± 0 a	29 ± 2 b
12	---	29 ± 6 b	28 ± 4 b
	Days in greenhouse from visible flower bud to first bloom (P ≤ 0.0001)		
0	---	40 ± 5 a	38 ± 0 b
6	---	37 ± 2 b	32 ± 3 c
12	---	37 ± 3 b	36 ± 1 bc
	Total days in greenhouse to first bloom		
0	---	74 ± 5	66 ± 0
6	---	71 ± 2	61 ± 4
12	---	66 ± 5	64 ± 4
	Plant height (cm) (P < 0.0001)		
0	---	55 ± 7 d	69 ± 10 bc
6	---	68 ± 4 bc	76 ± 5 b
12	---	67 ± 5 c	80 ± 8 a

[z]*All plants survived storage treatments.*

Table 4. *Growtb and flowering of* Lysimachia clethroides *after vernalization and photoperiod treatments.*[z] *Treatment n = 11.*

Storage (weeks) at 45.C	Photoperiod (h) 8	16	24
Percent emerged (n = no. plants emerged)			
0	73 (8)	27 (3)	36 (4)
6	82 (9)	73 (8)	90 (10)
12	100 (11)	100 (11)	100 (11)
Days in greenhouse to emergence (P < 0.0001)			
0	113 ± 26 a	104 ± 18 b	69 ± 4 c
6	68 ± 16 c	61 ± 10 c	46 ± 7 cd
12	19 ± 2 d	18 ± 4 d	18 ± 4 d
Percent of emerged plants flowering (n = no. plants flowered)			
0	0	66 (2)	50 (2)
6	0	50 (4)	100 (10)
12	0	100 (11)	100 (11)
Days in greenhouse from emergence to visible bud (P < 0.0001)			
0	---	102 ± 28 a	90 ± 11 a
6	---	81 ± 14 a	49 ± 4 b
12	---	46 ± 14 b	42 ± 7 b
Days in greenhouse from visible bud to first flower (P = 0.07)			
0	---	31 ± 2	31
6	---	30 ± 3	29 ± 3
12	---	27 ± 3	31 ± 2
Total days in greenhouse to first bloom			
0	---	204 ± 7	172 ± 14
6	---	153 ± 14	125 ± 6
12	---	91 ± 11	90 ± 7
Plant height (cm) (P < 0.0001)			
0	---	46 ± 34 c	75 ± 18 a
6	---	60 ± 11 c	78 ± 7 a–c
12	---	67 ± 8 bc	82 ± 3 ab
Number of flowering stems (P = 0.009)			
0	---	1	1
6	---	1.2 ± 0.4	3.1 ± 1.3
12	---	3.8 ± 1.6	3.6 ± 1.7

development in the 0- and 6-week cold treatments, a 24-h photoperiod significantly increased plant heights in all cold treatment groups.

Six and one-quarter months would be required to treat and force *Lysimachia clethroides* into bloom (12 weeks of cold storage to break dormancy, 3 weeks to activate growth, and 10 weeks for stems to grow and flowers to open). Plants dug and potted in late August could flower around 8 Mar. if this schedule began on 1 Sept. and the plants were forced at 15.5C night temperature and 16- or 24-h photoperiod. Longer stems produced at 24-h photoperiod would benefit cut flower production, for which stem length is important.

Phlox 'Fairy's Petticoat' is a long-day plant. Plants under an 8-h photoperiod remained vegetative; inflorescence development only occurred on plants grown beneath 16- and 24-h photoperiods (Table 5). Vegetative growth did emerge on plants grown beneath an 8-h photoperiod; however, it remained basal and never became reproductive. Under long-day conditions, flowering occurred on all plants that did not receive a cold treatment, indicating that *Phlox* 'Fairy's Petticoat' did not require cold treatment to emerge from dormancy or for flower development. However, 6 or more weeks of cold accelerated flower development slightly. Visually, the plants that had a cold treatment not only appeared more "robust" than those without a cold treatment, but also were significantly taller than those without a cold treatment. Therefore, cold improved quality of growth. A 24-h photoperiod treatment did not appear to accelerate growth, but produced significantly taller plants. Routine "Ban-rot" fungicide sprays were required to prevent powdery mildew.

To force phlox, plants at least 3 years old can be dug in mid- to late-August after peak flowering, divided, potted, and established before preforming cold and greenhouse forcing could begin. Young, strong divisions from the exterior of the clump produce superior plants. Removing spent inflorescences to avoid incidence of disease, retaining foliated stems on the divisions, and greenhouse-growing the new divisions for about 6 weeks under optimum conditions until established was important to successful completion of the crop. Best-finished plants result from treatment at 4.5C for 6 or more weeks, followed by 12 weeks of greenhouse forcing at 15.5C night temperature and at 16-or 24-h photoperiod. Therefore, if plants are divided and potted 15 Aug., cold-stored beginning 15 Oct., and greenhouse-forced 1 Dec., flowering could begin around 1 Mar. Increased flower stem length promoted by 24-h photoperiods during forcing would be beneficial for cut-flower marketing.

Echinops 'Taplow Blue' is a long-day plant that also responds to cold temperatures. Under an 8-h photoperiod, all plants remained vegetative. Inflorescence development occurred

Table 5. *Growth and flowering* ***of*** Phlox ***'Fairy's*** *Petticoat' after vernalization and photoperiod treatments. Treatment n = 11.*

Storage (weeks) at 4.5C	Photoperiod (h) 8	16	24
Percent survival			
0	73	73	82
6	73	73	91
12	64	55	73
Percent of survived plants flowering (n = no. plants flowered)			
0	0	100 (8)	100 (9)
6	0	100 (8)	100 (0)
12	0	100 (6)	100 (8)
Days in greenhouse to visible flower bud (P = 0.001)			
0	---	85 ± 17 a	83 ± 8 a
6	---	73 ± 0 ab	68 ± 4 b
12	---	72 ± 3 ab	69 ± 6 b
Days in greenhouse from visible flower bud to first bloom (P = 0.024)			
0	---	9 ± 2 ab	11 ± 2 ab
6	---	9 ± 2 b	10 ± 1 ab
12	---	12 ± 1 a	10 ± 1 ab
Total days in greenhouse to first bloom			
0	---	94 ± 18	94 ± 10
6	---	82 ± 12	78 ± 3
12	---	84 ± 2	79 ± 6
Plant height (cm) (P = 0.08)			
0	—	58 ± 7 b	66 ± 4 b
6	—	60 ± 5 b	83 ± 5 a
12	—	80 ± 6 a	89 ± 20 a

in long days without a cold treatment and at-an 8-h photoperiod after a cold treatment (Table 6). However, the most rapid and uniform inflorescence development only occurred on plants that received a 6- or 12-week cold treatment and grew at a 16- or 24-h photoperiods. This indicated *Echinops* 'Taplow Blue' requires a maximum of a 6-week cold treatment and daylength above the critical for complete flower induction, initiation, and development. Critical daylength is between 8 and 16 h. At all photoperiods, extended length of cold treatment accelerated the early stages of flower development, suggesting that cold applications reduce the requirement for long days.

out-of-season flowering of *Echinops* 'Taplow Blue' probably can best be achieved when forcing treatments begin at least 4.5 months before the desired flowering date (6 weeks cold storage and 12 weeks greenhouse forcing time). Plants are forced best at 15.5C night temperature and at 16- or 24-h photoperiod. Therefore, a Sep-

Table 6. *Growth and flowering of* Echinops *'Taplow Blue' after vernalization and photoperiod treatments. Treatment n = 11.*

Storage (weeks) at 4.5C	Photoperiod (h) 8	16	24
Percent survival			
0	100	100	91
6	100	100	100
12	100	100	100
Percent of survived plants flowering (n = no. plants flowered)			
0	0	73 (8)	90 (9)
6	45 (5)	100 (11)	100 (11)
12	82 (9)	100 (11)	100 (11)
Days in greenhouse to visible flower bud (P ≤ 0.0001)			
0	---	155 ± 9 a	55 ± 13 c
6	159 ± 9 a	20 ± 2 e	17 ± 0 e
12	123 ± 12 b	41 ± 0 d	26 ± 3 e
Days in greenhouse from visible flower bud to first bloom (P ≤ 0.0001)			
0	---	46 ± 6 c	61 ± 6 a
6	40 ± 3 c	60 ± 2 a	58 ± 3 a
12	40 ± 3 c	41 ± 2 c	52 ± 3 b
Total days in greenhouse to first bloom			
0	---	201 ± 1	116 ± 17
6	199 ± 8	80 ± 3	75 ± 3
12	163 ± 8	82 ± 2	78 ± 2
Plant height (cm) (P < 0.0001)			
0	---	54 ± 16 b	44 ± 5 b–d
6	70 ± 5 a	40 ± 4 d	44 ± 4 cd
12	70 ± 7 a	50 ± 4 bc	49 ± 4 b–d

tember-dug, field-grown plant could flower around 1 Mar. when cold storage begins 15 Oct.

Conclusions

To force a plant into bloom, it is necessary to provide artificially the required conditions necessary for development of the species. Horticulturists mimic environmental requirements to complete a plant's natural growth and development cycle. These studies and many other sources of information suggest that seasonal environmental differences found in the temperate zone provide herbaceous perennials the cue for the onset or breaking of dormancy and the onset of flowering. Seasonally changing factors include temperature, especially winter cold, and photoperiod.

Cold temperature exposure may have a three-fold effect for some perennial plants. First, cold may be necessary to release plants from dormancy *(Platycodon grandiflorus* 'Mariesii'; *Lysimachia clethroides).* If not received, underground root and root-like organs may be incapable of producing new foliar or floral growth. Second, cold temperatures may trigger flower induction; i.e., vernalization (Cant*panula persicifolia).* Growth patterns then change from foliar to floral. And third, cold can accelerate and synchronize growth, increase stem length, or improve flower quality, even when it is not required to initiate growth or induce flowering (Phlox 'Fairy's Petticoat'; *Echinops* 'Taplow Blue').

Appropriate daylength can start the flowering process. Many late-spring- and summer-flowering species only blossom when the period of light exceeds a critical length; i.e., long-day plants *(Coreopsis* 'Moonbeam'; *Lysimachia clethroides, Phlox* 'Fairy's Petticoat'; *Echinops* 'Taplow Blue').

Daylength requirements may or may not be combined with cold requirements. Some long-day perennials require cold to break root, rhizome, tuber, or crown dormancy *(Lysimachia clethroides).* Others are taller and more vigorous after they receive cold, but will flower without cold in long-day conditions (Phlox 'Fairy's Petticoat'). Long-day requirements may be replaced by a long, low-temperature treatment (Echinops'Taplow Blue').

Because the term "herbaceous garden perennial" comprises hundreds of species and cultivars from varied ecological and cultural backgrounds, it is difficult to provide one rule for forcing perennial garden plants. However, a general rule, with exceptions, can be made. Early spring-flowering plants that have a cold requirement, but lack a daylength requirement, are best forced in the greenhouse after they receive 12 weeks of cold. Flowers may appear in 3 weeks. Late-spring- and early summer-flowering plants that may or may not have a cold requirement and probably are long-day plants are best forced in the greenhouse under long-day conditions after they receive 6 weeks of cold. Late-summer-flowering types that do not have a cold requirement, but are still long-day plants, are best forced in the *green*house under long-day conditions.

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