Determination of Photoperiodic Response Group and Effect of Supplemental Irradiance on Flowering of Several Bedding Plant Species.

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Summary:
Flower induction of many plant species is synchronized temporally during the year by utilizing changes in day or night length. Commercial potted plant growers have used photoperiod manipulation to induce flowering of short-day plants on a year round basis. A lack of application of photoperiod to manipulate growth of current spring annuals has, in part, been due to the lack of information identifying the photoperiodic classifications of each species. This paper outlines a series of experiments that identified the photoperiodic group classifications and responses to supplemental irradiance of 28 spring annual species. No species studied were identified as obligate short-day plants. Most species were either obligate or facultative long-day plants. Species in which growers have traditionally had difficulty in producing marketable flowering plants in spring tended to be obligate long-day plants. In contrast, a number of species that tend to flower later in the season than desirable were identified as facultative short-day plants. In addition, species varied in their flowering response to supplemental lighting treatments. Leaf number below the first flower was affected by the addition of supplemental lighting under inductive conditions with approx. one half of the species studied.

Many annuals that flower late can be induced to flower earlier using lighting treatments.

Introduction:
Flower induction of many plant species is synchronized temporally during the year by utilizing changes in day or night length (Garner, and Allard, 1920). The common term for day/night length control of physiological phenomenon is 'photoperiodism'.

Photoperiodic responses of plants can be divided into three distinct groups: short-day, long-day, and day-neutral. Short-day plants require a night length longer than a specific number of hours for flower induction to occur. Long-day plants require a night length shorter than a specific number of hours for flower induction to occur. Day-neutral plant flower induction is unaffected by daylength but is often affected by the total irradiance a plant is exposed to during a 24-hour period (Bernier et al., 1993). Within the short and long-day photoperiodic groups, plants can exhibit a facultative (quantitative) or an obligate (qualitative) response. Flowering of plants with a facultative response is hastened by the identified photoperiod. In contrast, plants with an obligate response must have the identified photoperiod to flower.

Commercial potted plant growers have used photoperiod manipulation to induce flowering of short-day plants on a year round basis. For instance, *Dendranthema grandiflora* Tzvelv. (chrysanthemum) flowering is induced by pulling a cloth over plants to provide a short-day environment during long-day periods of the year. Seeley (1989) classified a number of bedding plant species into appropriate photoperiodic response groups. However, photoperiod manipulation in spring annual production is rare and is limited primarily to the shading of the obligate short-day plant *Tagetes erecta* L. seedlings after mid-March (in temperate regions) to insure flowering.

The increased emphasis on scheduling bedding plant production has been driven primarily by demands of mass marketers for consistency in product and the presence of flowers when plants are marketed. In addition, increased price pressures have led to a desire among growers to hasten flowering to reduce production costs. A lack of application of photoperiod to manipulate growth of current spring annuals has, in part, been due to the lack of information identifying the photoperiodic classifications of each species. This paper outlines a series of experiments that identified the photoperiodic group classifications and responses to supplemental irradiance of a number of spring annual species.

Materials and Methods

A series of experiments were conducted in St. Paul, Minnesota (U.S.A.) from Sept. 1, 1999 - May 1, 2000. Seed of *Ageratum houstonianum* Blue Danube', *Anethum graveolens* L. 'Mammoth', *Antirrhinum majus* Schott. 'Floral Showers Crimson', *Calendula officinalis* L. 'Calypso Orange', *Celosia plumose* L. 'Flamingo Feather Purple', *Cleome hassleriana* Chodat. 'Pink Queen', *Convolvulus tricolor* L. 'Blue Enchantment', *Cosmos bipinnatus* Cav. Ann. 'White Sensation' and 'Diablo', *Dianthus chinensis* L. 'Ideal Cherry Picotee', *Dimorphotheca pluvalis* DC., *Gazania rigens* L. 'Daybreak Red Stripe', *Gomphrena globosa* L. 'Bicolor Rose', *Helipterum roseum* Hook., *Lavatera trimestris* L. 'Silver Cup', *Limnanthes douglasii* R. Br., *Limonium sinuatum* (L.) Mill. 'Fortress Deep Rose', *Linaria maroccana* Hook. f., *Lobelia erinus* L. 'Crystal Palace', *Mimulus* x *hybridus* L. 'Magic', *Mirabilis jalapa* L., *Nemophila maculata* Benth. Ex. Lindl. 'Pennie Black', *Nicotiana alata* Link & Otto 'Domino White', *Nigella damascena* L. 'Miss Jekyll', *Origanum vulgare* L., *Papaver rhoeas* L., *Salvia splendens* F. Sellow ex Rheom. & Schult. 'Vista Red', *Silene armeria* L., *Tithonia rotundifolia* Mik. 'Fiesta del Sol', and *Zinnia elegans* Jacq. 'Peter Pan Scarlet' were germinated in a soilless media (Universal Mix, Strong-Lite Horticultural Prod., Pine Bluff, Ark., USA) under periodic mist (5 sec every 10 min). Air temperature was maintained at 22-24$\pm$2C. After germination and after cotyledons were horizontal to the media surface, 28 seedlings of each species were transplanted to a 4-pack plastic containers (1204 tray). A pack containing 4 seedlings of each species was then placed under each of six different lighting environments (see below) for photoperiod group identification and identification of flower induction responses to irradiance.

Lighting Treatments:

1) Short-day (8 h photoperiod (ambient daylight 0800-1600 HR))
2) Short-day + 25 μmol m^{-2} s^{-1} using high-pressure sodium lamps from 0800-1600 HR.
3) Short-day + 50 μmol m^{-2} s^{-1} using high-pressure sodium lamps from 0800-1600 HR.
4) Long-day (natural photoperiod + night interruption lighting from 2200-0200 HR using incandescent lamps (2 μmol m^{-2} s^{-1})).
5) Long-day + 25 μmol m^{-2} s^{-1} using high-pressure sodium lamps (0800-0200 HR).
6) Long-day + 50 μmol m^{-2} s^{-1} using high-pressure sodium lamps (0800-0200 HR).

Plants were watered as needed and fertilized continuously through the irrigation water with a balanced fertilizer (Miracle-Gro Excel 15-5-15 Cal-Mag, The Scotts Co., Marysville, OH, USA) at a rate of 200 mg/l N. Data were collected on leaf number below the first flower when the first flower opened on plants that flowered. Plants were classified as 'nonflowering' if flowering did not occur for 20 weeks. The experiment was replicated twice over time for most species. Data were analyzed through analysis of variance and mean separation using Tukey's HSD.

Results and Discussion

Photoperiodic Responses

Species varied in their response to lighting treatments across most photoperiod response groups (Table 1; pg. 15). Identification of photoperiodic response groups was based on the following criteria:

1) obligate short-day plant (flowering only under short-day conditions),
2) facultative short-day plant (lower leaf number under short-day conditions versus short-day plus night interruption lighting treatment),
3) obligate long-day plant (only flower under long-day conditions),
4) facultative long-day plant (lower leaf number under the ambient daylight (short-day) plus night interruption treatment (NI) compared to the short-day treatment,
5) day-neutral plant (equal leaf number under the short-day and ambient daylight (short-day) plus night interruption (NI) treatment).
6) Positive irradiance re-

There are 5 photoperiodic groups annuals fall into. In addition, there are 2 response groups to increased lighting.

sponse (reduced leaf number as irradiance increased under inductive conditions).

7) No irradiance response (no impact of increased irradiance under inductive conditions on leaf number).

No species studied were identified as obligate short-day plants. Most species were either obligate or facultative long-day plants. Species in which growers have traditionally had difficulty in producing marketable flowering plants in spring tended to be obligate long-day plants (*A. graveolens*, *H. roseum*, *L. trimestris*, *L. douglasii*, *L. erinus*, *M.* x *hybrida*, *N. damascena*, *S. armeria*). In contrast, species that tend to flower later in the season than desirable were identified as facultative short-day plants (*C. plumosa*, *C. bipinnatus*, *G. globosa*, *Z. elegans*).

Clearly, identification of photoperiodic requirements for flowering of a species allows more precise scheduling of these species. For instance, difficulty in flowering obligate/facultative long-day plants can be alleviated by delivery of long-day conditions when ambient short-day conditions are prevalent. In contrast, covering some species with black cloth to deliver short-day conditions under ambient long-day conditions would induce earlier flowering of obligate/facultative short-day plants. We are currently identifying the length of time and appropriate developmental time in which to deliver inductive treatments.

Lighting treatments will allow growers to prefinish seedlings for optimal performance in the finishing container.

Response to Irradiance

Species varied in their flowering response to supplemental lighting treatments (Table 1). Leaf number below the first flower was unaffected by the addition of supplemental lighting under inductive conditions with most species. However, supplemental lighting did hasten flowering (developmentally) of *C. tricolor*, *C. bipinnatus*, *G. rigens*, *L. trimestris*, *L. sinuatum*, *L. maroccana*, *N. maculata*, *N. alata*, *O. vulgare*, *P. rhoeas*, and *S. armeria*.

Prefinishing

Although early flowering is desirable with some species it is not always beneficial. Excessively early flowering induced by a combination of inductive photoperiod and irradiance conditions can reduce garden performance, an indeed, performance while finishing a crop in the greenhouse. Caution must be used when inducing flowering using lighting or black cloth as early induction of some species such as *P. nil* (unpublished data) can result in reduced garden performance as the plant 1) may not have sufficient foliage to support flowering, or 2) as in the case of vines, may not develop a desirable vining habit. Alternatively, excessively early flower induction of *Viola* x *wittrockiana* grown during the summer (high irradiance + long-days) can result in very early flowering prior to branching and reduces greenhouse flat filling and garden performance (personal observation). Lastly, although earlier flower is beneficial for some seedlings destined to be finished in bedding plant flats, those seedlings destined for lager containers may not branch sufficiently to fill the container.

Young plant growers will likely use this information to more precisely schedule spring annual crops. Grouping of species by photoperiodic and/or irradiance needs for early flower induction can allow growers to effectively time flowering of these crops as is done with many short-day requiring potted plant crops. Lighting treatments will also vary with the desired finishing size of a marketable container. Further research is needed to identifying photoperiodic response groups, timing of lighting treatments (developmentally and the needed duration for an impact on induction), and ultimate impact on garden performance.

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Table 1. Response of spring annual species flowering to lighting treatments. Data on leaf number below the first open flower are reported as well as appropriate photoperiodic and irradiance classifications. Short-day (8 hour photoperiod)(SD), Long-day (natural photoperiod + night interruption lighting from 2200-0200 HR using incandescent lamps (2 $umol\ m^{-2}\ s^{-1}$)) (NI). Supplemental lighting (+25 or +50 $umol\ m^{-2}\ s^{-1}$) was delivered during short-day (short-day treatments 0800-0400 HR) or as a day extension (0800-0200 HR) (long-day treatments). Letters denote mean separation comparisons across lighting treatments utilizing Tukey's HSD (alpha=0.05)

Plant	Lighting Treatment						Classification	
	Short-Day			Long-Day				
	SD	+25	+50	NI	+25	+50	Photoperiod	Irradiance
Ageratum houstonianum L. 'Blue Danube'	9a [z]	9a	9a	8a [y]	8a	7b	FLDP [x]	0 [v]
Anethum graveolens L. 'Mammoth'	- [u]	-	-	8a	7a	7a	OLDP	0
Antirrhinum majus Schott. 'Floral Showers Crimson'	9b	11b	10b	6a	-	7a	FLDP	0
Calendula officinalis 'Calypso Orange'	16b	16b	15b	12a	13a	14a	FLDP	0
Celosia plumosa L. 'Flamingo Feather Purple'	15a	14a	16a	-	-	-	OSDP	0
Cleome hassleriana Chodat 'Pink Queen'	29b	31b	31b	25a	25a	25a	FLDP	0
Convolvulus tricolor L. 'Blue Enchantment'	-	-	-	-	14a	15a	DNP	+
Cosmos bipinnatus Cav. Ann. 'White Sensation'	8a	7a	9a	25b	26b	20c	FSDP	+
Cosmos bipinnatus Cav. Ann. 'Diablo'	6a	7a	6a	8b	9b	9b	FSDP	0
Dianthus chinensis L. 'Ideal Cherry Picotee'	10b	11b	11b	8a	8a	8a	FLDP	0
Dimorphotheca pluvalis DC.	-	-	-	-	22a	36b	DNP	-
Gazania rigens L. 'Daybreak Red Stripe'	-	-	-	8a	5b	6b	OLDP	+
Gomphrena globosa L. 'Bicolor Rose'	5a	5a	5a	7b	6b	7b	FSDP	0
Helipterum roseum Hook.	-	-	-	67a	54a	61a	OLDP	0
Lavatera trimestris L. 'Silver Cup'	-	-	-	9a	6b	7b	OLDP	+
Limnanthes douglasii R. Br.	-	-	-	9a	9a	5b	OLDP	
Limonium sinuatum (L.) Mill. 'Fortress Deep Rose'	37b	36b	32a	32a	31a	31a	FLDP	0
Linaria maroccana Hook.f.	23c	28c	-	14b	7a	11ab	FLDP	+
Lobelia erinus L. 'Crystal Palace'	-	-	-	8a	7a	8a	OLDP	0
Mimulus x *hybridus* L. 'Magic'	-	-	-	4a	4a	4a	OLDP	0
Mirabilis jalapa L.	-	-	-	-	10a	10a	OLDP/DNP	0
Nemophila maculata Benth. Ex Lindl. 'Pennie Black'	-	-	28c	19a	8b	-	DNP	+
Nicotiana alata Link & Otto 'Domino White'	33b	32b	33b	33b	15a	16a	DNP	+
Nigella damascena L. 'Miss Jekyll'	-	-	-	6a	7a	5a	OLDP	0
Origanum vulgare L.	-	-	-	-	8a	6b	DNP	+
Pavaver rhoeas L.	-	-	-	-	20a	15b	DNP	+
Salvia splendens F. Sellow 'Vista Red'	9b	8a	8a	7a	7a	8a	FLDP	0
Silene armeria L.	-	-	-	15b	14ab	11a	OLDP	+
Tithonia rotundifolia Mill. 'Fiesta Del Sol'	12b	12b	11a	-	10a	11a	FLDP	0
Zinnia elegans Jacq. 'Peter Pan Scarlet'	5a	5a	5a	7b	6ab	6ab	FSDP	0

z '-' denotes that no plants flowered

y Mean leaf number

x Photoperiod classifications: FSDP (facultative short-day plant); FLDP (facultative long-day plant); OLDP (obligate long-day plant; DNP (day neutral plant).

v Irradiance classifications: '+' (supplemental irradiance hastened induction developmentally); '0' (no response to irradiance).

(Lily Leaf Counts—continued from page 11)

Table 1. Yearly average counts of the number of inner and outer scales and leaves initiated during late October, prior to the commencement of vernalization, for 8-9" (20-22 cm) bulbs of *Lilium longiflorum* 'Nellie White'.

Year	Number of outer scales	Number of inner scales	Number of leaves initiated
1984	38.4	55.0	20.2
1985	38.4	45.3	25.7
1999	47.9	40.7	13.2
2000	45.2	49.4	23.4
Average	**42.5**	**47.6**	**20.2**

Table 2. Yearly average counts[1] of the number of leaves on case cooled and controlled temperature forcing (CTF) *Lilium longiflorum* 'Nellie White' plants (8-9", 20-22cm bulbs). Leaf counts were conducted as soon as possible after flower bud initiation, on January 28th (approximately) of each year.

Year	Case cooled	CTF
1969	----[2]	89.0
1970	89.6	90.5
1971	69.6	89.6
1972	70.2	90.0
1973	67.8	83.0
1974	80.0	87.3
1975	73.8	77.4
1976	71.9	82.3
1977	56.3	65.1
1978	65.6	74.5
1979	----	79.3
1980	----	69.7
1981	----	76.8
1982	----	70.8
1983	----	76.8
1984	----	83.2
1985	----	93.6
1986	87.2	84.1
1987	82.0	93.0
1999	85.2	89.4
Average	**74.9**	**82.3**

[1]Counts from 1969-1987 are from H.F. Wilkins, Professor Emeritus in floriculture, University of Minnesota.
[2] Few, if any, 'Nellie White' Easter lilies were produced via case cooling during these years.

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