*Chapter 13.*

# Light Effects on Bedding Plants

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This chapter presents information on day length and lighting effects on growth and flowering of bedding plants and vegetable and herb transplants. Understanding the effect of light intensity (irradiance) on plant quality and flowering is important when making decisions on greenhouse shading and supplemental lighting. Understanding the effect of day length and plant age on bedding plant, vegetable, and herb flowering is critical in scheduling these crops and in most cases, to maximize flowering. Conversely, inhibiting flowering is often desirable with herb crops and bedding plant/potted plant stock plants.

## 13.1 Photosynthesis in Bedding Plants

Plant size, or biomass, increases because plants use sunlight to convert carbon dioxide ($CO_2$) and water into sugar that is used to drive growth; we call this process photosynthesis. Generally, as photosynthesis increases, crop quality increases. Plants grown with high versus low light generally have thicker stems, greater mass, more flowers, less stem elongation and more branching.

## Irradiance and photosynthesis

We control photosynthesis in greenhouse crops by manipulating irradiance, $CO_2$ concentration, temperature, mineral nutrition and water supply. In general, photosynthesis increases as irradiance increases to some maximum level, when a higher irradiance does not further increase photosynthesis. Essentially, the chemical process that drives photosynthesis cannot go any faster, or is saturated. It is very important to know at what irradiance photosynthesis is saturated for a crop because lighting above this intensity will be of no benefit and wastes electricity. The photosynthetic response varies among species. For example, increasing irradiance to 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ increases photosynthesis in vinca (Catharanthus roseus), but further increasing it to 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ does not further increase photosynthesis (**Figure. 13.1**). For geranium (Pelargonium ×hortorum), increasing irradiance above 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ did not result in further increases in photosynthesis (**Figure. 13.2**).

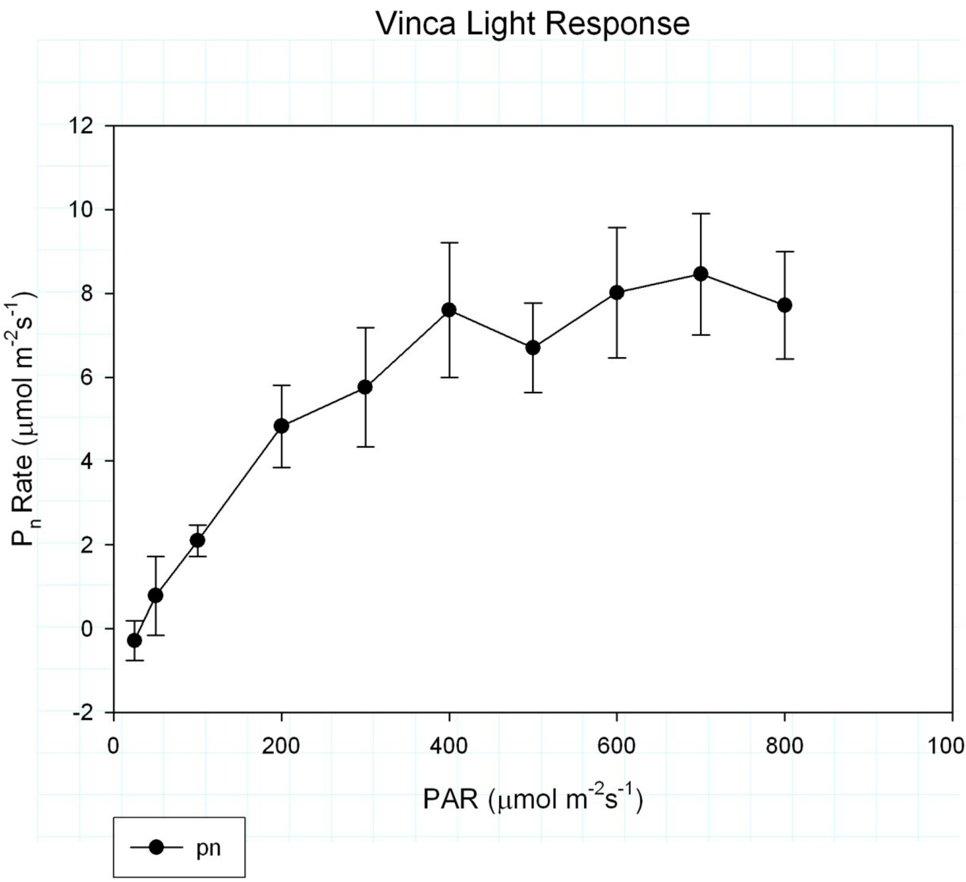


**Figure 13.1. Photosynthesis rate of vinca (Catharanthus roseus) in response to increasing irradiance (PAR). Plants were grown at 68 °F (20 °C) with ambient $CO_2$. Data were collected from individual leaves.**

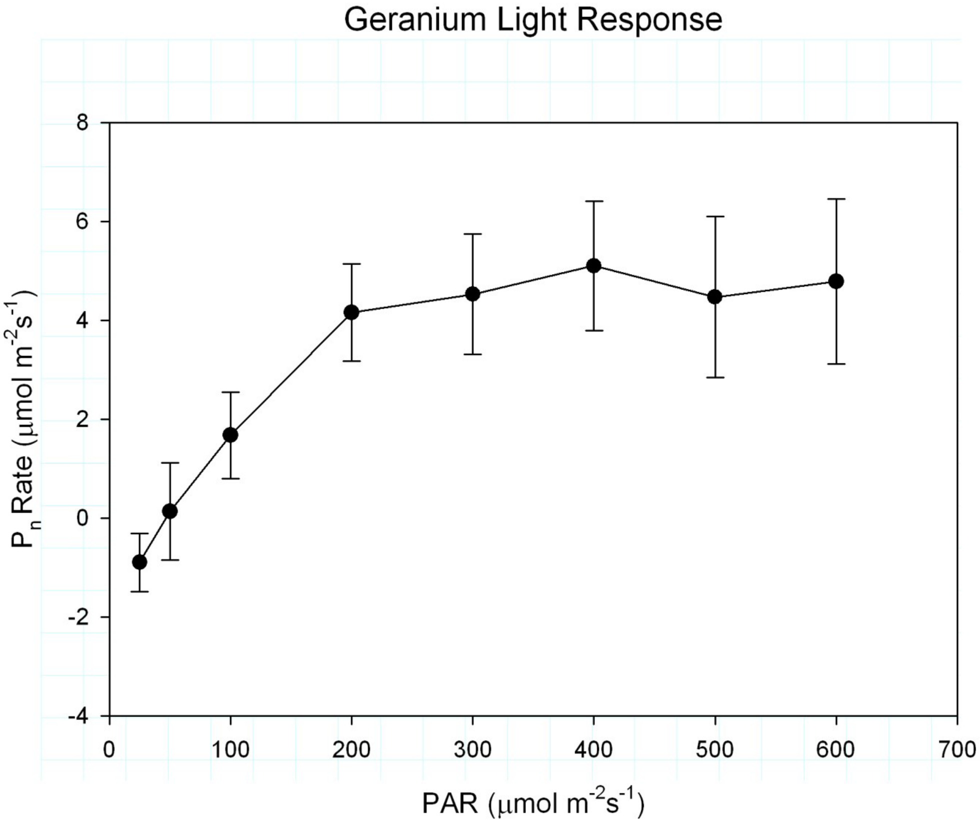


**Figure 13.2. Photosynthesis rate of geranium (Pelargonium) in response to increasing irradiance (PAR). Plants were grown at 68 °F (20 °C). Data were collected from individual leaves.**

Photosynthesis measurements are taken from a single leaf, not a whole plant. Since leaves in a canopy shade each other, the maximum beneficial irradiance for a crop where there is shading within the canopy may be higher than that for a single leaf (higher light level than shown in **Figure. 13.1** and **13.2**). As the goal is to maximize photosynthesis of every leaf and many leaves are within a canopy, it may be beneficial to light to maximize photosynthesis using a light meter that rests below plant height in the canopy. Also, the maximum irradiance for a crop increases as a crop grows together on a bench, or in a tray, as more internal shading occurs.

On sunny days, supplemental lighting can often be shut off because irradiance levels exceed the irradiance where photosynthesis saturates. In contrast, growers will often find that they over shade with retractable curtains or by applying too much whitewash to the outside of greenhouses.

### Carbon dioxide

As mentioned before, $CO_2$ is used by plants as an ingredient in photosynthesis to make sugar. Similar to irradiance, increasing CO2 generally increase photosynthesis up to some maximum level. However, in contrast to irradiance, increasing CO2 concentrations above this level can decrease photosynthesis. In general, growers will see increased photosynthesis if greenhouse CO2 levels are increased to approximately 700-1,200 ppm (**Figure. 13.3**).

Often it is assumed that $CO_2$ levels in greenhouses are the same as outdoors when not supplementing with $CO_2$; this is often not the case in the north. When closed greenhouses are used with minimal venting during cold winter months, greenhouse $CO_2$ levels decrease over time during the day. Why? Because the plants use $CO_2$ for photosynthesis and not enough new $CO_2$ is entering the greenhouse to replace this. As a result, $CO_2$ levels can drop to <250 ppm during the day within a canopy. This drop is greater on sunny days because more photosynthesis is occurring.

The response of photosynthesis to increasing CO2 differs with species (Boldt et al., 2011). For example, increasing CO2 concentration from 400 to 800 ppm results in a 100% increase in photosynthesis for petunia (Petunia ×hybrida; **Figure. 13.3A**) and a 200% increase in photosynthesis for cyclamen (Cyclamen persicum; **Figure. 13.3B**). Notice that for petunia there is little photosynthesis benefit of adding $CO_2$ above 700 ppm (**Figure. 13.3A**) whereas for cyclamen it was beneficial to add $CO_2$ up to 1,000 ppm (**Figure. 13.3B**). Also, increasing $CO_2$ from 200 to 400 ppm (outdoor levels) increased photosynthesis substantially. We believe that part of the benefit in plant quality (mass) seen when growing plants with an open roof greenhouse is related to plants being exposed to higher $CO_2$ levels resulting in more photosynthesis. See Chapter 9 for more information on $CO_2$ enrichment.

**Figure 13.3. Photosynthesis rate in response to carbon dioxide concentration for petunia (A) and cyclamen (b) grown at 68 °F (20 °C). Data were collected from individual leaves.**

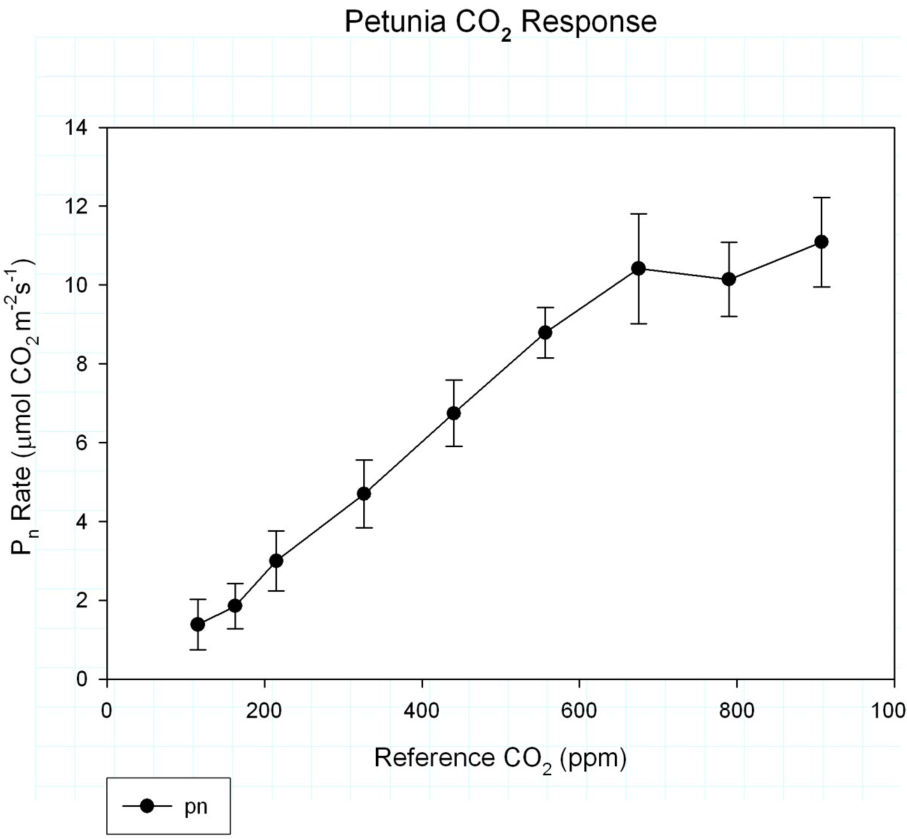


**Figure 13.3A**

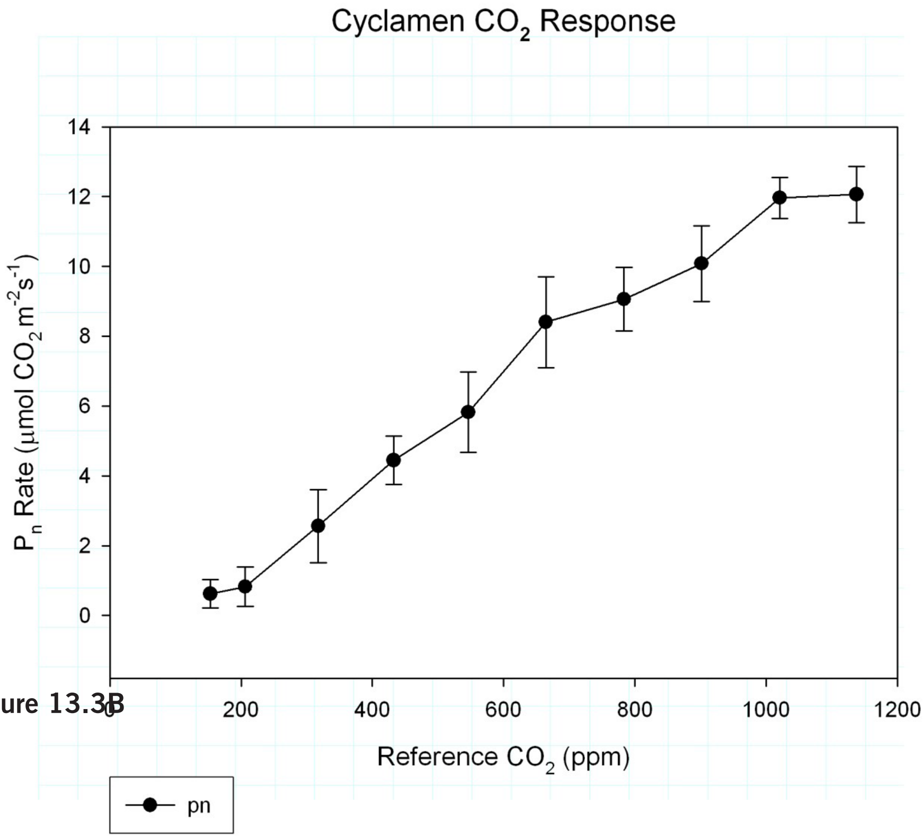
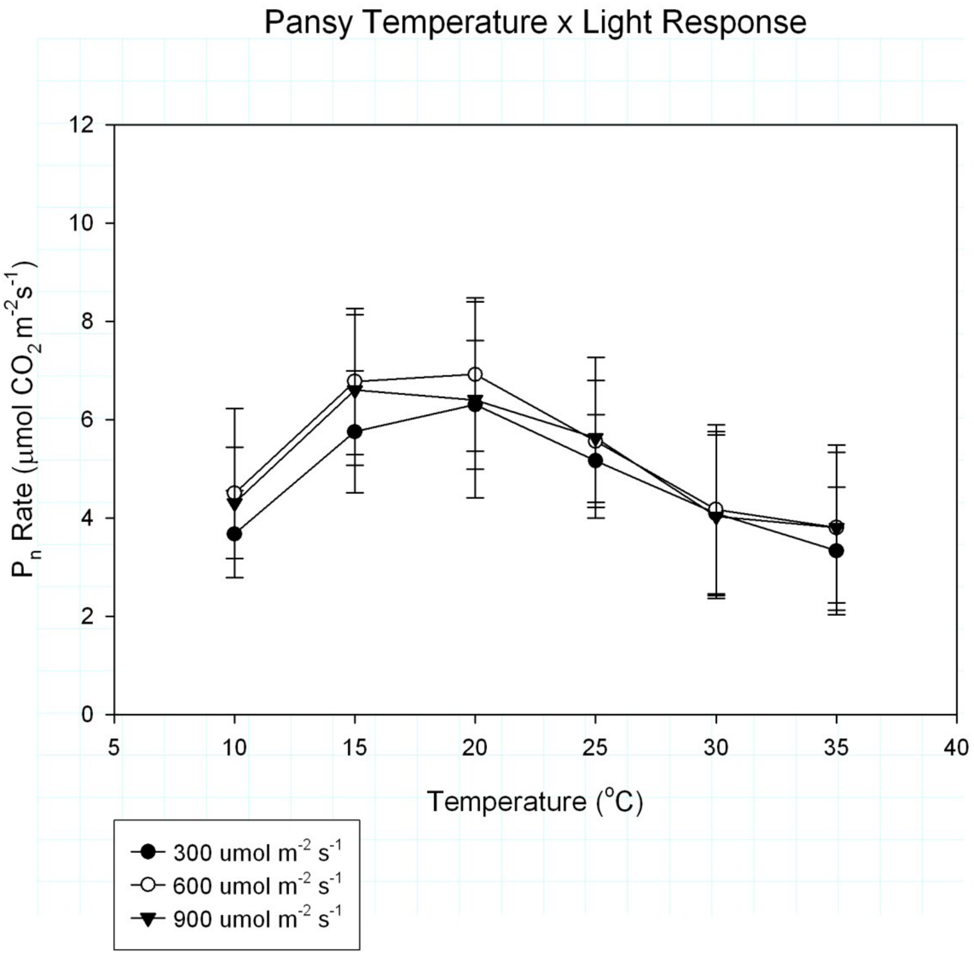


Figure 13.3B

## Temperature

As discussed in Chapter 2, temperature drives the rate of chemical reactions in plants; photosynthesis is one such chemical reaction. As temperature increases, the rate of photosynthesis increases until some maximum temperature is reached. Different bedding plants have different maximum temperatures for photosynthesis (Warner and Erwin, 2002). We can see in **Figure. 13.4** that pansy (Viola ×wittrockiana) photosynthesis increases as temperature increases up to 68°F (20°C) and then begins to decline whereas for poinsettia (Euphorbia pulcherrima), optimum temperature for photosynthesis is around 86°F (30°C). The pansy example indicates that high temperature depression of photosynthesis is likely more common than many of us realize during daytime greenhouse conditions.

**Figure 13.4. Photosynthesis rate of pansy (A) and poinsettia (B) in response to increasing temperature grown at 68 °F (20 °C). Data were collected from individual leaves at light intensities of 300 to 900 µmol·m–2·s–1.**



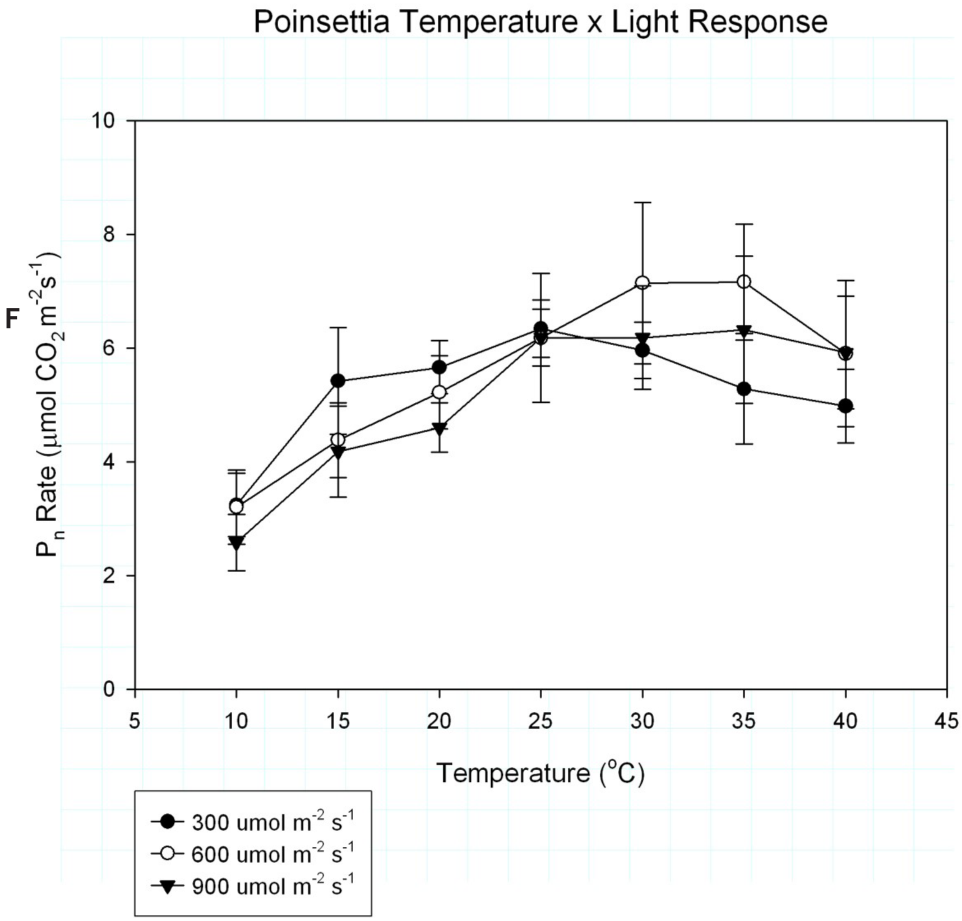


Figure 13.4B

## Practical implications

Bedding plant photosynthesis can be limited if irradiance, CO2, or temperature is limited. For instance, the benefits of supplemental lighting will be limited if CO2 levels are too low or if temperature is too high. Each factor must be taken into consideration to maximize the efficacy of another. What is obvious is that what limits photosynthesis in different locations differs.

Let's look at the differences in what limits photosynthesis in different parts of the country.

In the Southern U.S., particularly Florida, light levels can be moderate, temperatures can be warm and humidity can be high. Here, plants are likely limited more by low light (from shading) and high temperature than low $CO_2$ because plants often are grown under open ventilation. However, this can be a drawback because it is difficult to increase greenhouse/shadehouse $CO_2$ levels above the ambient 400 ppm. Also, it is difficult to decrease air temperature because humidity levels are high and evaporative cooling can be less effective. Therefore, growers in the South should focus on not limiting photosynthesis by excessive shading and by providing sufficient ventilation to keep plant temperatures from becoming too hot.

In arid regions with high light, such as southern California, plants and greenhouse environments can be heated by the high light, but the low humidity allows for effective cooling with evaporative cooling to optimize plant temperature. However, adding $CO_2$ above outdoor levels is difficult. In general, supplemental lighting is not necessary.

In more temperate regions, such as the northern U.S. and Canada, plant photosynthesis is likely limited more by low light and low $CO_2$ in closed greenhouses than by high temperature or too much light. Here, supplemental lighting during the winter is important, as is ensuring that $CO_2$ levels are at or above ambient levels.

Regardless of location, commercial shade curtains generally decrease irradiance by at least 50%, which limits photosynthesis more than many realize.

## 13.2 Stages of Plant Development and Juvenility

Plants are often incapable of being induced to flower immediately after germination. When a plant is incapable of flowering early in development it is referred to as juvenile. At some point, a plant develops (or ages) to a point where it switches from the juvenile to a mature phase. When a plant is mature, it can be induced to flower.

The duration of the juvenile phase varies widely across plant species, but is generally short for most annual bedding plants, lasting from only a few days to several weeks after germination. In contrast to annual bedding plants, some perennial crops must grow for months before they switch from the juvenile to mature phase as discussed in Chapter 14.

It is important to understand when a plant becomes mature to schedule flowering. Unfortunately, there is usually no visible change in appearance of the plant when it attains the mature phase. A way that we can quantify plant age is by counting how many leaves have unfolded on the main shoot. A plant with more leaves unfolded than another of the same species is developmentally more mature.

Breeding of many seed-propagated annuals, such as petunia and pansy, has focused partly on reducing flowering time to reduce production costs. Therefore, there has likely been a progressive selection of plants with a shorter juvenile period. As a result, many annual bedding plants need to unfold four or fewer leaves before they can be induced to flower. Thus, it is possible for plants to be induced to flower earlier than desired, which can result in low quality plants at retail and poor performance in the landscape (**Figure. 13.5**).

**Figure 13.5. Cosmos 'Sonata Pink' grown under night-interruption lighting (long days, left) or short days (right) beginning immediately after germination. The premature flowering and minimal vegetative mass of the short day-grown plant can result in poor garden performance.**

We have seen several examples of this such as with celosia (Celosia plumosa) and cosmos (Cosmos bipinnatus), both facultative short-day plants. Previously, this premature flowering was attributed to drought or some other stress during the seedling stage. However, our research has determined that some celosia cultivars become mature as early as 10 days after germination, even before the first true leaves appear (**Figure. 13.6**) (Warner, 2009). Therefore, it is important to provide long-day conditions if the natural day length is short (less than 12 hours) to prevent undesirably early flowering.

**Figure 13.6. Ten-day-old seedlings of celosia 'Fresh Look Red', a short-day plant, are capable of perceiving flower-inducing short days. Celosia seedlings should be grown under long day conditions to prevent premature flowering.**

## 13.3 Day length Effects on Flowering

The effect of photoperiod on flowering is discussed in Chapter 4, so here we elaborate on how to apply this information to bedding plant production. Flowering responses to day length, or photoperiod, can be divided into three groups: short-day, long-day and day-neutral flowering responses.

- 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 day length.

Within the short- and long-day photoperiodic groups above, plants can have a facultative (quantitative) or an obligate (qualitative) photoperiod response. Flowering of plants with a facultative response is hastened by the identified photoperiod, but flowering will eventually occur under any photoperiod. In contrast, plants with an obligate response must have the identified photoperiod to flower at all.

In some cases, plants can flower earlier or later than desired under natural photoperiods. For instance, it is not uncommon for celosia, cosmos, or China aster (Callistephus chinensis) seedlings to bloom well before they reach a marketable size. It is also common for cosmos, blue salvia (Salvia farinacea), and snapdragon (Antirrhinum majus) to flower later than desirable. The problem identified in each case can be fixed by giving plants the right photoperiod at the right time.

### Photoperiod manipulation

Manipulation of day length to affect flowering of bedding plants is becoming increasingly common, and these techniques are discussed in detail in Chapter 10. Continuing interest in manipulating bedding plant flowering is primarily being driven by the desire of growers to flower plants earlier in the spring to broaden their marketing window. Still other growers want to ensure that annual and perennial crops are flowering during peak sales times because consumers tend to buy more plants in flower. In addition, aside from inducing earlier flowering, increased price pressures have led growers to hasten flowering to reduce production costs. Lastly, some growers delay flowering until plants “bulk up” to ensure that a saleable size is reached.

The greatest impediments to successful day length manipulation are 1) the lack of lighting/blackout cloth facilities to manipulate day length, 2) a lack of information on how day length and supplemental photosynthetic lighting affects flowering of current species and cultivars, and 3) a lack of understanding of how temperature interacts with day length and lighting to affect flowering and photosynthesis.

Blackout cloth/curtains are used to exclude light to achieve short day length during times of the year when the natural photoperiod is longer than desired. When the day length longer than the natural photoperiod is desired, day-extension or night-interruption lighting is used. See Chapter 14 for information on how to create short days or deliver low-intensity, photoperiodic lighting to create long days.

### Short-day plants

Chrysanthemum (Chrysanthemum morifolium) and poinsettia are examples of common short-day plants; they induce flowers naturally as nights get longer, after mid-summer or early fall, respectively. In our screening experiments at the University of Minnesota, we found few short-day plants among common bedding plants grown (Mattson and Erwin, 2005; **Table 13.1**). Growers use blackout cloth on African marigolds (Tagetes erecta) when days get longer (March to October) to ensure plants bloom early. Plumed celosia is a facultative short-day plant, and will flower more quickly if grown under short days (**Figure. 13.6**). Some of the early (undesirable) flowering common in celosia seedlings in early spring is probably because young seedlings receive short days and induce flowers too early. Three other economically important bedding plants that flower earlier under short days are cosmos, zinnia (Zinnia elegans), and many cultivars of sunflower (Helianthus annuus). Excessively early flowering in cosmos can be quite common early in the season. In contrast, the late flowering – seen in some celosia and cosmos after April – is a result of the lack of inductive short days.

Other short-day plants, such as the hyacinth bean vine (Dolichos lablab; an obligate short-day plant) will not flower unless it receives short days. This is why hyacinth bean vine does not flower until September in Minnesota; seedlings germinate under long days in April/ May and don't initiate flowers until fall. Similarly, morning glory (Pharbitis nil, a short-day plant) will have delayed flowering if early seedling growth occurs under long days (April/May). It is possible to have blooming mina vine (Ipomoea lobata; **Figure. 13.7**) or morning glory plants for sale in April with earlier short-day treatments (8-hour day length).

**Figure 13.7. The effect of photoperiod and increasing light intensity on the irradiance- indifferent, short-day plant celosia 'Flamingo Feather Purple.' Plants were grown at a 68 °F day and 65 °F night (20 °C/ 18 °C) under ambient daylight conditions (left) or with supplemental high-pressure sodium lighting at 25 (center) or 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (right).**

Short day plant flowering can be delayed by high night temperatures even when plants are grown under short days. Specifically, if plant temperature is higher than 72°F to 74°F (22°C to 23°C) about 8 hours after the onset of darkness (usually around midnight), flowering can be delayed. This delay in flowering is often referred to as heat delay, which also occurs in chrysanthemum and poinsettia.

In general, our research indicates that annuals classified as short-day plants can be induced to flower at a younger age, and with fewer photoinductive cycles, than annuals classified as long-day plants, although there is considerable variation within each group. Once mature, many short-day plants can be induced to flower with as few as 5 to 10 short days, while most long-day crops we have evaluated required at least 2 to 3 weeks of long days for flower induction to occur.

**Figure 13.8. Effect of short days (achieved using blackout cloth from 5pm to 8am daily, left) versus long days (ambient spring light with night-interruption lighting from incandescent lamps, delivered from 10 pm to 2 am at 2 μmol·m$^{-2}$·s$^{-1}$, right) on the obligate short-day plant mina vine.**

## Long-day plants

Many bedding plants are long-day plants (**Table 13.1**). Some common examples of facultative long-day plants are pansy, Mexican sunflower (Tithonia rotundifolia 'Sundance') and blue salvia (**Figure. 13.9**). Many other bedding plants are obligate long-day plants, including bachelor's buttons (Centaurea cyanus 'Blue Boy'), California poppy (Eschscholzia californica 'Sundew') and 'Purple Wave' petunia. Growers often have delayed flowering when growing obligate long-day plants under natural days in the spring, as some plants only naturally flower when the days are at least 13 to 14 hours long. In contrast, pansy grown during the summer can bloom too early and before they reach a desirable size.

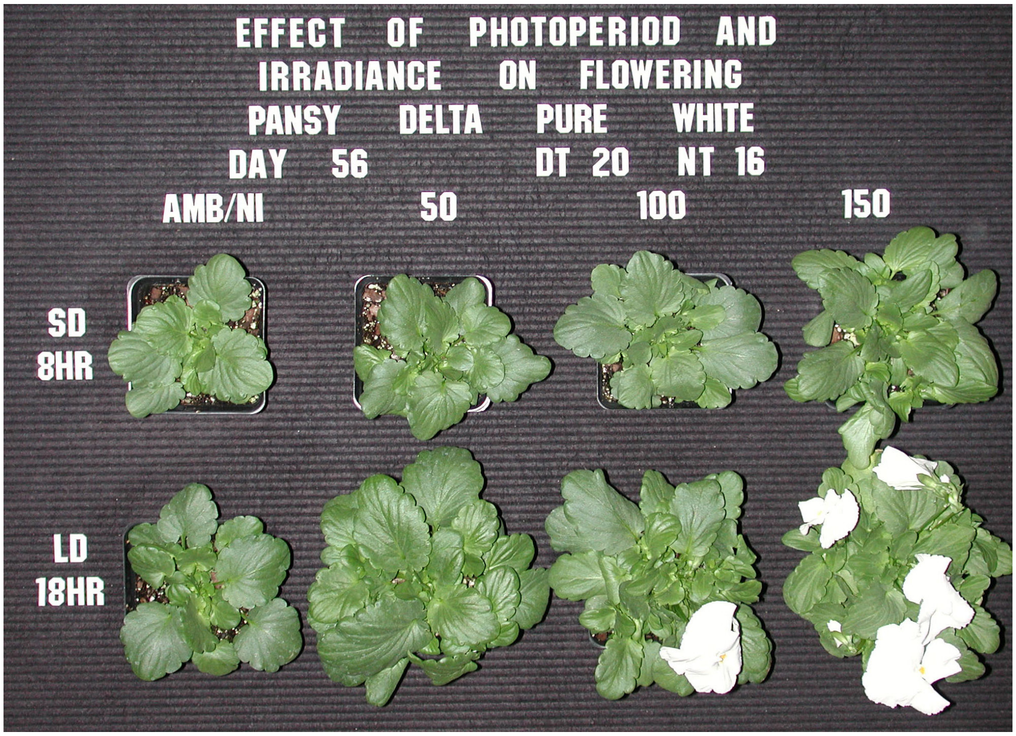


**Figure 13.9. The effect of long days (LD) and short days (SD) and increasing irradiance on flowering of the facultative long-day plants pansy 'Delta Pure White' (top) and blue salvia 'Strata' (bottom). Irradiance levels were ambient daylight with a 4-hour night interruption (AMB / NI), or ambient plus 50, 100 or 150 µmol·m$^{-2}$·s$^{-1}$ from high-pressure sodium lamps. Daily light integrals ranged from 6.4 to 20.2 mol·m–2·d–1. Plants were grown at a 68 °F day and 61 °F night.**

**Table 13.1. Photoperiodic and irradiance classifications of bedding plants based on average leaf number below the first open flower. Data are summarized from a variety of trade, scientific, and original research findings. Photoperiod classifications are as follows: FSDP (facultative short-day plant); FLDP (facultative long-day plant); OSDP (obligate short-day plant); OLDP (obligate long-day plant); DNP (day-neutral plant). Irradiance classifications are as follows: FI (facultative irradiance response: supplemental irradiance hastened induction developmentally); II (irradiance indifferent response; increasing irradiance did not hasten flowering developmentally). "?" means that we found conflicting results between different references or between cultivars. "—" means there was no reported research on the effect of irradiance on flowering.**

| Scientific name | Common name | Photoperiod response[1] | Irradiance response[2] |
|---|---|---|---|
| Abutilon × hybridum | flowering maple | DNP | — |
| Achimines hybrids | achimenes | DNP | — |
| Acroclinium roseum | strawflower | OLDP | II |
| Ageratum houstonianum | flossflower | FLDP | — |
| A. houstonianum 'Blue Danube' | | FLDP | II |
| A. houstonianum 'Tall Blue Horizon' | | FLDP | — |
| Alcea rosea | hollyhock | LDP | — |
| Amaranthus hybridus 'Pygmy Torch' | smooth amaranth | DNP | II |
| Ammi majus | bishop's weed | OLDP | II |
| Angelonia angustifolia | summer snapdragon | DNP | — |
| Anethum graveolens | dill | O/FLDP | II |
| A. graveolens 'Mammoth' | | OLDP | II |
| Anisodontea × hypomandarum | cape mallow | FLDP | — |
| Antirrhinum majus | snapdragon | FLDP | FI |
| A. majus 'Floral Showers Crimson' | snapdragon | FLDP | — |
| A. majus 'Spring Giants' | snapdragon | FLDP | — |
| A. majus 'Twinny' Series | snapdragon | FLDP | FI |
| Argyranthemum frutescens | marguerite daisy | DNP | |
| Asclepias curassavica | Mexican butterfly weed | DNP | FI |
| A. tuberosa | butterfly weed | OLDP | — |
| Asperula arvensis 'Blue Mist' | blue woodruff | OLDP | II |

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|---|---|---|---|
| Begonia × hiemalis | rieger begonia | O/FSDP | — |
| B. tuberhybrida | tuberous begonia | OLDP | — |
| B. semperflorens | wax begonia | DNP | FI |
| Bougainvillea spp. | paper flower | FSDP | FI |
| Bracteantha bracteata | strawflower | DNP | — |
| Browallia viscosa ‘Amethyst’ | browallia | FSDP | FI |
| Calceolaria herbeohybrida | pocketbook plant | FLDP | — |
| Calendula officinalis | pot marigold | O/FLDP | — |
| C. officinalis ‘Calypso Orange’ | | FLDP | II |
| Calibrachoa ‘Colorburst Violet’ | million bells | FLDP | — |
| C. ‘Liricashowers Rose’ | | FLDP | — |
| Callistephus chinensis | China aster | FLDP | — |
| Capsicum annuum | pepper | DNP | — |
| Carpanthea pomeridiana ‘Golden Carpet’ | golden carpet | DNP | II |
| Catanache caerulea ‘Blue’ | cupid’s dart | OLDP | FI |
| Catharanthus roseus | vinca | DNP | — |
| Celosia argentea | cockscomb | FSDP | — |
| C. plumosa ‘Flamingo Feather Purple’ | | OSDP | II |
| Centaurea spp. | bachelor’s buttons | O/FLDP | — |
| C. cyanus ‘Blue Boy’ | | OLDP | II |
| Centranthus macrosiphon | spurred valerian | DNP | FI |
| Cleome hassleriana | spider flower | DNP/OLDP | — |
| C. hassleriana ‘Pink Queen’ | | FLDP | II |
| C. hassleriana ‘Rose Queen’ | | DNP | FI |
| C. spinosa | spiny spider flower | FSDP | — |
| Clerodendrum thomsoniae | bleeding heart vine | DNP | — |
| C. × speciosum | red bleeding heart vine | DNP | — |
| Cobaea scandens | cup and saucer vine | DNP | II |

|  |  |  |  |
|---|---|---|---|
| Convulvulus tricolor ‘Blue Enchantment’ | morning glory | DNP | FI |
| Cosmos astrosanguineus | chocolate cosmos | FLDP | — |
| C. bipinnatus ‘Diablo’ |  |  |  |
|  | Mexican aster | FSDP | II |
| C. bipinnatus ‘Early Wonder” |  | FSDP | — |
| C. bipinnatus ‘Sensation White’ |  | FSDP | FI |
| C. sulphureus | yellow cosmos | OSDP | — |
| Cosmos sulphureus ‘Cosmic’ Series | yellow cosmos | FSDP | II |
| Collinsia heterophylla | Chinese houses | FLDP | II |
| Coriandrum sativum | cilantro | OLDP | II |
| Crossandra infundibuliformis | firecracker flower | DNP | — |
| Cucumis sativus | cucumber | DNP | — |
| Dahlia × hybrida | dahlia | FSDP | — |
| Dendranthema × grandiflorum | chrysanthemum | FSDP | — |
| Dianthus barbatus | sweet William | DNP | — |
| D. chinensis ‘Ideal Cherry Purple’ | pinks | FLDP | II |
| Diascia hybrids | diascia | DNP | — |
| Dimorphoteca aurantica ‘Mixed Colors’ | cape marigold | DNP | II |
| D. aurantica ‘Salmon Queen’ |  | OLDP | — |
| Dolichos lablab | hyacinth bean | OSDP | II |
| Eschscholzia californica | California poppy | FLDP | II |
| Evolvulus glomeratus | evolvulus | LDP | — |
| Exacum affine | Persian violet | DNP | — |
| Fuschia × hybrida | hybrid fuschia | OLDP | — |
| F. ‘Gartenmeister’ |  | DNP | — |
| Gallardia × grandiflora | blanketflower | FLDP | — |
| Gallardia × grandiflora | blanketflower | FLDP | II |
| G. × grandiflora ‘Goblin’ |  | OLDP | — |
| Gazania rigens ‘Daybreak Red Stripe’ | treasure flower | OLDP | FI |
| Gazania rigens ‘New Day’ Series | gazania | DNP | II |
| Gerbera jamesonii | gerbera daisy | FSDP | — |

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|---|---|---|---|
| Gomphrena globosa 'Bicolor Rose' | globe amaranth | FSDP | II |
| Gypsophilia elegans | baby's breath | F/OLDP | — |
| G. paniculata | | F/OLDP | — |
| G. paniculata 'Snowflake' | | OLDP | — |
| Helianthus annuus | sunflower | DNP/FSDP | — |
| H. annuus 'Big Smile' | | FSDP | — |
| H. annuus 'Elf' | | FSDP | — |
| H. annuus 'Pacino' | | FSDP | — |
| H. annuus 'Sunbright' | | FSDP | — |
| H. annuus 'Sundance Kid' | | DNP | — |
| H. annuus 'Sunrich Orange' | | FSDP | — |
| H. annuus 'Sunspot' | | FSDP | — |
| H. annuus 'Teddy Bear' | | FSDP | — |
| H. debilis 'Vanilla Ice' | | FLDP | II |
| Hibiscus cisplatinus | | DNP | — |
| H. laevis | halberd-leaf rosemallow | OLDP | — |
| H. moscheutos | swamp mallow | OLDP | FI |
| H. radiates | monarch rosemallow | OSDP | — |
| H. rosa-sinensis | Chinese hibiscus | DNP | — |
| H. trionum | flower-of-an-hour | FLDP | — |
| Impatiens balsamina | garden balsam | OSDP | — |
| I. hawkeri | New Guinea impatiens | DNP | — |
| I. walleriana | seed impatiens | DNP | — |
| Ipomoea lobata | mina vine | OSDP | II |
| Ipomoea × multifida 'Scarlet' | cardinal climber | FSDP | II |
| I. spp. | | FSDP | — |
| Ipomopsis rubra 'Hummingbird Mix' | standing cypress | OLDP | II |
| Jamesbrittania hybrids | bacopa | DNP | — |
| Lanatana camara | shrub verbena | DNP | — |
| L. montevidensis | | DNP | — |
| Lathyrus odoratus 'Royal White' | sweet pea | OLDP | FI |

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|---|---|---|---|
| Lavatera trimestris ‘Silver Cup’ | annual mallow | OLDP | FI |
| Legousia speculum-veneris | Venus’ looking glass | OLDP | II |
| Leonotis menthaefolia | mint scented lion’s tail | DNP | — |
| Leptosiphon hybrida | | OLDP | II |
| Lilium spp. | lily | FLDP | — |
| Limnanthes douglasii | poached egg plant | OLDP | FI |
| Limonium sinuata ‘Fortress Deep Rose’ | statice | FLDP | II |
| L. sinuata ‘Heavenly Blue’ | | FLDP | II |
| Linaria maroccana | toadflax | FLDP | FI |
| Linum perenne | blue flax | OLDP | FI |
| Lobelia erinus | trailing lobelia | OLDP | — |
| L. erinus ‘Crystal Palace’ | | OLDP | II |
| L. × speciosa | | FLDP | — |
| L. × speciosa ‘Compliment Scarlet’ | | FLDP | — |
| Lobularia maritime | sweet alyssum | DNP | — |
| Lycopersicon esculentum | tomato | DNP | — |
| Matthiola hybrids | stock | FLDP | — |
| M. longipetala ‘Straight Sensation’ | evening stock | DNP | II |
| Mimulus × hybridus ‘Magic’ | monkeyflower | OLDP | II |
| Mirabilis jalapa | four o’clock flower | OLDP | II |
| Nemophila maculata ‘Pennie Black’ | five-spot | DNP | FI |
| N. menziesii | baby blue eyes | DNP | II |
| Nicotiana alata | flowering tobacco | DN/FLDP | — |
| N. alata ‘Domino White’ | | DNP | FI |
| N. ‘Havana’ Series | | FLDP | II |
| N. ‘Perfume’ Series | | FLDP | FI |
| N. ‘Tinkerbell’ | | FLDP | FI |
| N. langsdorfii | | FLDP | FI |
| N. paradoxa ‘Bird’ Series | | FLDP | FI |
| N. sylvestris | | OLDP | II |

| | | | |
|---|---|---|---|
| Nigella damascena ‘Miss Jekyll’ | love-in-a-mist | OLDP | II |
| Ocimum americanum ‘Blue Spice’ | basil | FSDP | FI |
| Ocimum basilicum ‘Genovese’ | basil | DNP | FI |
| Ocimum basilicum ‘Lime’ | | DNP | FI/II |
| Ocimum basilicum var. thyrsiflora ‘Siam Queen’ | Thai basil | FSDP | FI |
| Ocimum gratissimum ‘Cinnamon’ | cinnamon basil | DNP | FI |
| Oenethera pallida ‘Wedding Bells’ | pale evening primrose | OLDP | II |
| Origanum majorana | | OLDP | II |
| Origanum heracleoticum | | OLDP | II |
| Origanum vulgare | oregano | DNP | FI |
| Osteospermum hybrids | African daisy | FLDP | — |
| Oxypetalum caerulea ‘Blue Star’ | tweedia | DNP | FI |
| Pelargonium × domesticum | regal geranium | FLDP | — |
| P. × hortorum | zonal geranium | DNP | FI |
| P. peltatum | ivy geranium | DNP | — |
| Pentas lanceolata | Egyptian starflower | FLDP/DNP | — |
| Perilla frutescens | green shiso | ?SDP | — |
| Petunia × hybrida | petunia | FSD/OLDP | — |
| P. × hybrida ‘Cascadia Charme’ | | FSDP | — |
| P. × hybrida ‘Cascadia Improved Charlie’ | | FLDP | — |
| P. × hybrida ‘Doubloon Blue Star’ | | FLDP | — |
| P. × hybrida ‘Fantasy Pink Morn’ | | OLDP | — |
| P. × hybrida ‘Marco Polo’ | | FLDP | — |
| P. × hybrida ‘Petitunia Bright Dream’ | | FLDP | — |
| P. × hybrida ‘Purple Wave’ | | OLDP | FI |
| P. × hybrida ‘White Storm’ | | FLDP | — |
| Phacelia campanularia | desert bells | DNP | II |
| P. tanacetifolia | lacy phacelia | FLDP | II |
| Pharbitis nil | morning glory | FSDP | — |
| Phlox chinensis | annual phlox | FLDP | — |
| Polemonium viscosum | sky pilot | OLDP | II |
| Portulaca grandiflora | moss rose | DNP | — |

|  |  |  |  |
|---|---|---|---|
| P. oleracea | flowering purslane | DNP | — |
| Primula malacoides | fairy primrose | OSDP | — |
| P. obconica | German primrose | DNP | — |
| P. × polyantha | English primrose | DNP | FI |
| Rosa × hybrida | rose | DNP | FI |
| Rudbeckia spp. | black-eyed Susan | OLDP | — |
| Salpiglossus sinuata | painted tongue | FLDP | — |
| Salvia coccinea ‘Reddy White Surprise’ |  | FLDP | FI |
| Salvia coccinea ‘Summer Jewel’ Series |  | DNP | FI |
| Salvia farinacea | mealy sage | FLDP | FI |
| S. splendens ‘Vista Red’ | scarlet sage | FLDP | II |
| Sanvitalia procumbens | Mexican creeping zinnia | FSDP | II |
| Scabiosa columbaria | pincushion flower | ?DNP | — |
| Scaevola aemula | fan flower | DNP | — |
| Silene armeria ‘Elektra’ | catchfly | OLDP | FI |
| Sinningia speciosa | gloxinia | DNP | — |
| Solenostemon spp. | coleus | ?SDP | — |
| Solidago spp. | goldenrod | SDP | — |
| Sutera cordata | bacopa | DNP | — |
| Streptocarpus × hybridus | cape primrose | DNP | FI |
| Stevia rebaudiana | stevia | OSDP | II |
| Tagetes erecta | African marigold | FSDP | — |
| T. patula | French marigold | DNP | — |
| T. tenuifolia | signet marigold | FSDP | — |
| Thunbergia alata | black-eyed Susan vine | DNP | II |
| Thymus pulegioides |  | FLDP | FI |
| Tithonia rotundifolia | Mexican sunflower | FLD/FSDP | — |

| | | | |
|---|---|---|---|
| T. rotundifolia ‘Fiesta Del Sol’ | | FLDP | II |
| T. rotundifolia ‘Sundance’ | | FSDP | FI |
| Torenia fournieri | wishbone flower | ?DNP | — |
| Verbascum phoeniceum | mullein | DNP | II |
| Verbena × hybrida | verbena | ?LDP | — |
| Viguiera multiflora | goldeneye | FLDP | II |
| Viola tricolor | violet | F/OLDP | II |
| V. × wittrockiana | pansy | FLDP | FI |
| V. × wittrockiana ‘Freefall’ | | FLDP | FI |
| Zea mays | corn | DNP | — |
| Zinnia angustifolia | creeping zinnia | DNP | — |
| Z. elegans ‘Benary Giant Deep Red’ | zinnia | FLDP | — |
| Z. elegans ‘Exquisite Pink’ | | FSDP | II |
| Z. elegans ‘Oklahoma’ | | FSDP | — |
| Z. elegans ‘Peter Pan Scarlet’ | | FSDP | II |
| Z. haageana ‘Aztec’ | | FSDP | II |
| Z. marylandica ‘Double’ Series | | FSDP | FI |

Adapted from Mattson and Erwin (2005) and Currey et al. (2011)

Long-day plants can be induced to flower early if they are given long days during photoperiods with lighting when the day length is shorter that that required for flower induction. The efficacy of night-interruption lighting and day-extension lighting to induce flowering of long-day plants is affected by temperature. Specifically, as temperature decreases from 68°F, the efficacy of the night lighting decreases. For instance, we have found that the duration of night-interruption lighting needs to be increased from 4 to 6 hours, or the intensity of that light needs to be brighter than 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$, when night temperatures are between 50°F to 60°F.

## Day-neutral plants

A number of bedding plants are day neutral (**Table 13.1**). These species flower at approximately the same time whether grown under short or long days. For example, amaranthus (Amaranthus hybridus

‘Pygmy Torch’), stock (Matthiola longipetala ‘Starlight Scentsation’) and black-eyed Susan vine (Thunbergia alata) are all day-neutral plants.

## 13.4 Irradiance and Daily Light Integral

Irradiance is an instantaneous measurement of photosynthetically active radiation (PAR) – that portion of light that can be used for photosynthesis and is expressed as $\mu mol \cdot m^{-2} \cdot s^{-1}$. As discussed in Chapter 1, irradiance can be measured frequently and over a 24-hour period so that the cumulative daily amount of PAR, the daily light integral (DLI), can be calculated. Therefore, irradiance quantifies how much light is available for photosynthesis at any one moment, and DLI quantifies how much light is available for photosynthesis over a 24-hour period.

DLI affects time to flower of some seed-propagated bedding plants. For instance, there is a historical “rule-of-thumb” from the 1980’s that every day that you provide supplemental lighting to a seed geranium seedling (beginning soon after germination) reduces the time to flower by one day. Supplemental lighting can increase plant mass under low light levels in the greenhouse because it increases photosynthesis and thus plant quality. How supplemental lighting affects flowering among bedding plants is less clear.

We use two terms, or response groups, to describe whether plants can be induced to flower earlier developmentally (lower leaf number on the main stem) by providing supplemental lighting when the natural DLI is low:

- Facultative irradiance response refers to plants in which extra photosynthetic lighting reduces the leaf number below the first flower (i.e., flowering occurs earlier developmentally; the length of the juvenile phase is reduced).

- Irradiance indifferent response refers to plants in which extra photosynthetic lighting has no effect on the leaf number below the first flower (i.e., extra lighting does not hasten flowering developmentally; the juvenile phase is not reduced).

Plants with a facultative irradiance response occur within the three major photoperiodic response groups, including long-day, day-neutral, and short-day plants. For example, the facultative long-day plant blue salvia (**Figure. 13.9B**) and the day-neutral plant seed geranium are both facultative irradiance plants and flower more quickly as DLI increases from 6.4 to 29.2 mol·m$^{-2}$·d$^{-1}$ (within their prescribed photoperiod). **Table 13.1** shows irradiance responses for many bedding plants that were identified at the University of Minnesota.

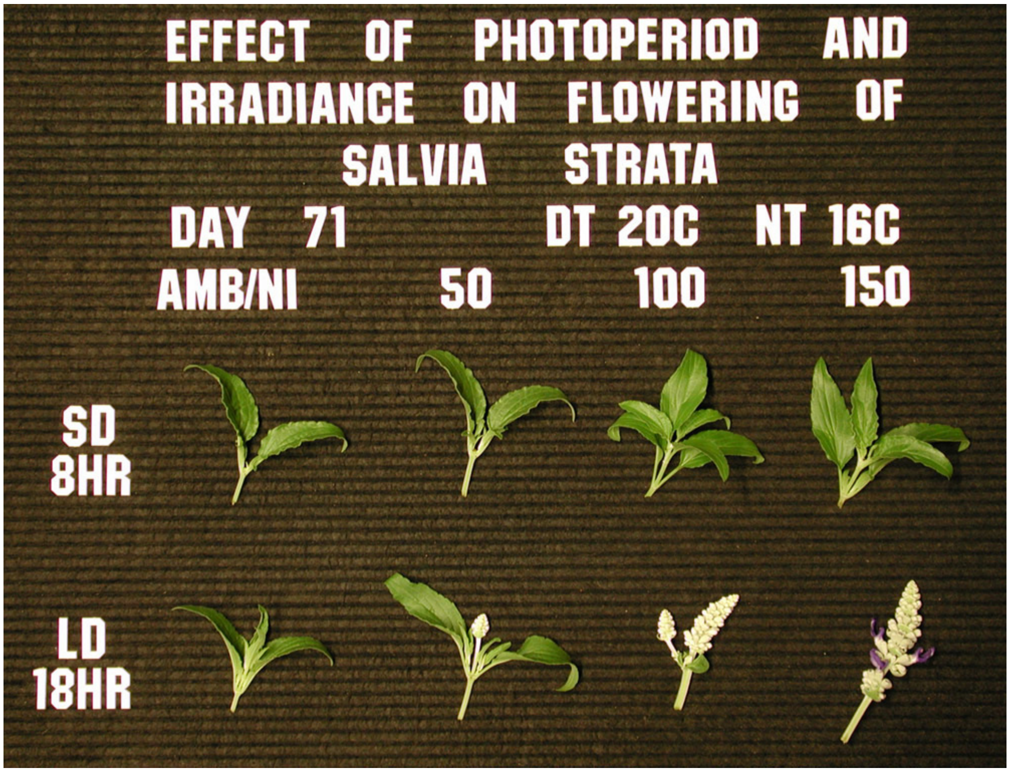
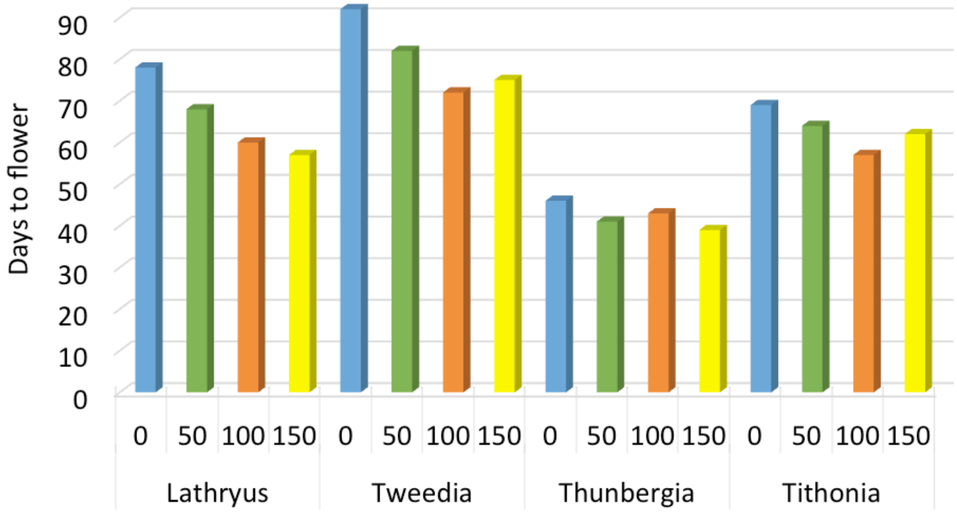


**Figure 13.9B**

There is some confusion with how lighting affects earliness in flowering with many crops. In general, providing supplemental light by high intensity discharge (HID) lamps such as high-pressure sodium (HPS) almost always results in earlier flower. Why? When you add supplemental lighting, plants are heated from infrared light emitted by the HID lamps, therefore plants are simply warmer, develop (or unfold leaves) faster and thus flower earlier. This occurs with both irradiance indifferent and facultative irradiance plants.

**Figure. 13.10** shows that although leaf number below the first flower was not greatly influenced by adding supplemental lighting, time to flower decreased with the irradiance-indifferent plants black-eyed-Susan vine (Thunbergia) and Mexican sunflower (Tithonia) as supplemental irradiance increased from 0 to 150 μmol·m$^{-2}$·s$^{-1}$ from HPS lamps – likely due to plant heating from the lamps.

In contrast, with facultative-irradiance plants, supplemental lighting accelerates flowering because the juvenile phase length is reduced and they develop faster (leaves unfold faster) because of lamp heating. For instance, **Figure. 13.10** shows that as irradiance increased, time to flower decreased from 78 to 57 days and 92 to 75 days on the facultative-irradiance response plants sweet pea (Lathyrus odoratus) and tweedia (Oxypetalum coeruleum).



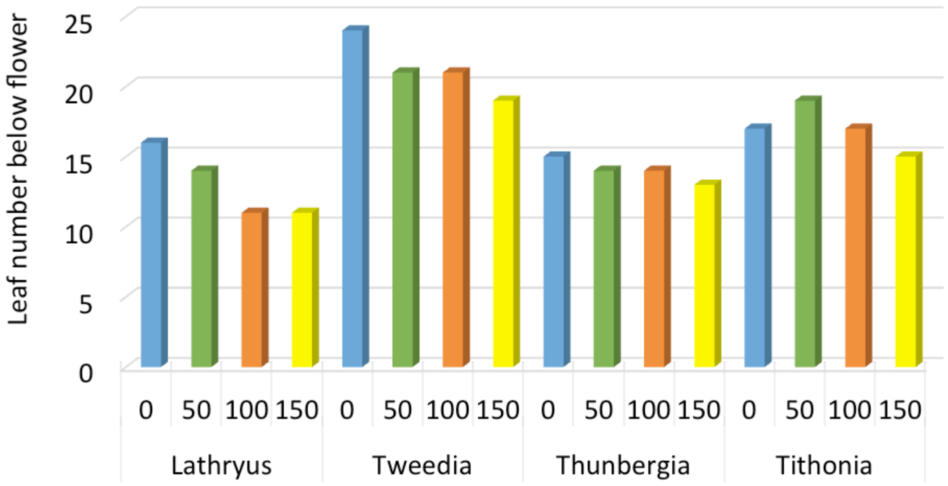


**Figure 13.10. The effect of increasing irradiance from 0 to 150 µmol·m–2·s–1 for 18 hours daily from high-pressure sodium lamps on time to flower (top) and leaf number below the first flower (bottom) of four species. Lathyrus (sweet pea) and Tweedia are facultative irradiance response plants; increasing irradiance reduced the number of leaves below the first flower. Thunbergia (black-eyed-Susan vine) and Tithonia (Mexican sunflower), are irradiance indifferent; increasing irradiance did not reduce leaf number below the first flower. Ambient daily light integral (sunlight) was 12 to 13 mol·m–2·d–1 during the experiment.**

In many cases, heating with lamps is not a cost-efficient way to accelerate plant development. Therefore, unless you need more plant mass on a seedling, it may not be economical to add supplemental lighting to irradiance indifferent bedding plant seedlings.

We do not really understand why increased irradiance can reduce juvenile phase length with some species. Is juvenile phase length reduced by supplemental lighting because there is more sugars available for flower induction? Does supplemental lighting alter the hormonal balance in plants? Answers to these questions could help us to decrease, or increase, juvenile period length through breeding efforts and environmental treatments.

How much supplemental lighting is needed to get earlier flowering on facultative irradiance plants? At the University of Minnesota, we determined facultative irradiance crops such as petunia, pansy and blue salvia flower earlier (have a lower leaf number) when DLI increases to approximately 8 to 10 mol·m$^{-2}$·d$^{-1}$ (Mattson and Erwin, 2005; **Table 13.1**). Further increasing the DLI did not reduce leaf number below the first flower. Subsequent research conducted at Michigan State University on different crops also determined that 8 to 10 mol·m$^{-2}$·d$^{-1}$ was the target minimum DLI on a number of annual bedding plants.

## 13.5 What Does This Mean For You?

To improve the reliability flowering of bedding plants, educate yourself on when each species is developmentally mature and what conditions (day length and irradiance) induce it to flower. Once plants are mature, either induce flowering to achieve the earliest possible flowering, or delay flowering to increase plant size before inducing them to flower.

In addition, when the DLI is low (less than 8 to 10 mol·m$^{-2}$·d$^{-1}$), use supplemental lighting to increase mass, or quality, of seedlings. Once the DLI target is reached in a day, supplemental lights can be turned off unless needed for photoperiodic lighting. See Chapter 8 for guidelines on supplemental lighting and technology options and costs.

You can induce early flowering if you place seedlings in the appropriate day length and irradiance environment after a seedling is mature (unfolded enough leaves to be competent for flower initiation). For instance, with the facultative short-day plant cosmos, days to flower decreased from 89 to 33 days by growing seedlings under short days versus long days (**Table 13.2**). In contrast, the facultative long-day plant blue salvia flowered in 98 days under long days instead of 128 days under short days.

Table 13.2. Photoperiodic response and days to flower under short days or long days from experiments at the University of Minnesota. Plants were grown at a 68/61°F day/ night (20/16°C) Short-day plants had black out cloth pulled from 5:00 p.m. to 8:00 a.m. daily to create a 9-hour day; long-day plants had night-interruption lighting from incandescent lamps at 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ from 10:00 p.m. to 2:00 a.m. daily. Ambient daily light integral (sunlight) was 12 to 13 $mol \cdot m^{-2} \cdot d^{-1}$. "-" denotes plants had not flowered after 20 weeks.

| | | Days to flower | |
|---|---|---|---|
| Plant | Photoperiod response | Short day | Long day |
| African Daisy | Day neutral | 110 | 103 |
| Amaranthus | Day neutral | 17 | 17 |
| Ammi | Obligate long day | - | 48 |
| Asperula | Obligate long day | - | 47 |
| Bachelor's Buttons | Obligate long day | - | 46 |
| Black Eyed Susan Vine | Day neutral | 46 | 46 |
| Blue Salvia | Facultative long day | 125 | 98 |
| California Poppy | Obligate long day | - | 70 |
| Cardinal Creeper | Facultative short day | 43 | 72 |
| Carpanthea | Day neutral | 119 | 118 |
| Catananche | Obligate long day | - | 87 |
| Centranthus | Day neutral | 92 | 78 |
| Cleome | Day neutral | 115 | 93 |
| Collinsia | Facultative long day | 81 | 52 |
| Cosmos | Facultative short day | 33 | 89 |
| Cup and Saucer Vine | Day neutral | 100 | 92 |
| Flax | Obligate long day | - | 91 |
| Foam and Eggs Flower | Obligate long day | - | 125 |
| Globe Amaranth | Facultative short day | 76 | 96 |
| Hyacinth Bean Vine | Obligate Short Day | 59 | - |
| Ipomopsis | Obligate long day | - | 88 |
| Legousia | Obligate long day | - | 101 |
| Leptosiphon | Obligate long day | - | 68 |
| Mexican Sunflower | Facultative short day | 59 | 69 |

| | | | |
|---|---|---|---|
| Mina Vine | Obligate short day | 31 | - |
| Nemophila | Day neutral | 97 | 87 |
| Oenothera | Obligate long day | - | 98 |
| Oxypetalum | Day neutral | 100 | 92 |
| Pansy | Facultative long day | 80 | 73 |
| Phacelia | Day neutral | 29 | 22 |
| Phacelia | Obligate long day | - | 59 |
| Polemonium | Obligate long day | - | 89 |
| Purple Wave Petunia | Obligate long day | - | 74 |
| Sanvitalia | Facultative short day | 33 | 44 |
| Silene | Obligate long day | - | 67 |
| Statice | Facultative long day | 89 | 58 |
| Stock | Day neutral | 91 | 63 |
| Sunflower | Facultative long day | 102 | 83 |
| SweetPea | Obligate long day | - | 78 |
| Verbascum | Facultative long day | 152 | 137 |
| Viguiera | Obligate long day | - | 65 |
| Zinnia | Facultative short day | 44 | 63 |

Adapted from Mattson and Erwin (2005)

However, very early flowering is not always desirable; you may stimulate flowering on a seedling before it establishes enough size to support large and numerous flowers, or to adequately fill a container. We have seen several examples of very early flower induction decreasing finished plant quality with crops such as celosia and cosmos (both facultative short-day plants) early in spring, as discussed previously. Therefore, with these crops it is important to provide long-day conditions after germination if the natural day length is short to “bulk” plants for 1 to 3 weeks, depending on desired finish plant size, and then stop photoperiod lighting to induce flowering under natural short days.

In contrast to celosia and cosmos, many annual bedding plants are long-day plants and can bloom too early when they receive long day lighting during the plug stage. With these species, it is important to initially grow crops under short-day conditions in the plug and then grow them under long-day conditions to induce flowers.

Irradiance is also important. If a plant is a long-day, facultative irradiance plant, provide long days during winter to achieve at least 8 to 10 $mol \cdot m^{-2} \cdot d^{-1}$. If the DLI from natural light is greater than 8 to 10 $mol \cdot m^{-2} \cdot d^{-1}$, then deliver low-intensity lighting to create long days. If DLI is less than 8 $mol \cdot m^{-2} \cdot d^{-1}$, extend the day with supplemental lighting to provide long days and increase the DLI to at least 10 $mol \cdot m^{-2} \cdot d^{-1}$. In contrast to long-day facultative irradiance plants, long-day irradiance indifferent plants can be induced to flower by photoperiodic (long day) lighting only; supplemental lighting does not accelerate flowering but it can increase crop quality.

Based on much of this information, bedding plant growers can effectively schedule crops to flower whenever they choose. This allows for early or delayed flowering to expand the marketing window, increase sales, and increase plant quality.

Acknowledgements

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