Fundamentals of Flowering in Plants:
Supplemental Lighting and Earliness of Flowering

John Erwin, Neil Mattson and Ryan Warner
Department of Horticultural Science, University of Minnesota

Part II

Introduction:

In Part I, we discussed how light intensity (irradiance) and supplemental lighting can affect flowering of seed-propagated bedding plants. This article is the second article to focus on the same topic and provides additional information on how the need for supplemental lighting varies in different parts of the country. In addition, how species differ in how much light they can use is presented. Lastly, how high day temperatures can affect photosynthetic rate and plant quality is discussed. Future articles will show new results on how daylength affects flowering of many bedding plants.

Impact of Light on Flowering:

Increased lighting, or irradiance, can reduce the length of the juvenile period with some species, thereby reducing the time to flower. We do not really understand how this occurs. Is juvenile period length reduced by supplemental lighting because there is more food, or photosynthates, available for flower induction? Photosynthesis is the process where a plant utilizes sunlight and carbon dioxide in the air to make sugars, or food. 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.

Juvenile period length varies in bedding plants. The juvenile period of bedding plants can be nearly non-existent or be as long as months with some of the perennial species we grow in the industry. Additional lighting is most effective in reducing juvenile period length on those species that have a longer juvenile period such as perennials, seed geraniums, and 'Purple Wave' petunias.

The juvenile period of most common bedding plants (herbaceous annuals in temperate climates) is between 1 and 2 weeks. We measure the 'maturity' of a plant by counting the number of leaves below a flower. In many cases, bedding plants are mature when we can see 3 unfolded leaves on a seedling (1-2 weeks after germination). We mention this because the length of the juvenile period of a crop gives us some indication of the maximum amount we could shorten production time! For instance, if the juvenile period on a 'White Storm' petunia is nearly nonexistent, then providing supplemental lighting will reduce crop time minimally. In contrast, if the juvenile period of 'Purple Wave' petunias is 2 weeks, then it may be possible to reduce crop time by a maximum of 2 weeks by shortening the juvenile period using lighting.

Classification of Lighting Responses with Flowering:

We identified two new terms to describe how irradiance and/or daily light integral affect flowering: facultative irradiance and irradiance indifferent response groups.

1) When a plant has a facultative irradiance response, extra lighting reduces the leaf number below the first flower, i.e. flowering occurs earlier developmentally.
2) When a plant has an irradiance indifferent response, extra lighting has no effect on the leaf number below the first flower, i.e. extra lighting does not hasten flowering developmentally.

Many of the bedding plants we grow did not flower earlier developmentally when supplemental lighting was added to ambient light (St. Paul, Minnesota (fall and spring)) in the range of light levels we studied (6.5 – 13.5 moles per day). Any affect of lighting on these crops was restricted to possible increases in plant size or mass through increased photosynthesis. Therefore, at total light levels at or above 6.4 moles per day crops such as dill, cosmos, gomphrena, lobelia and zinnia will not flower earlier if supplemental lighting is provided (irradiance indifferent) (Table 1). In contrast, crops such as snapdragon, cleome, hibiscus (perennial), petunia, lavatera and blue salvia (Figure 1) will flower earlier as light intensity increases above 6.4 to 29.2 moles per day (facultative irradiance response) (Table 1).

Facultative irradiance plants occur in most photoperiodic response groups studied. We will discuss which plants fit into which photoperiodic groups in a future article. However, as an example for now, the facultative long-day plant, and day neutral plants Blue Salvia and Cleome, respectively, are facultative irradiance plants and will flower more quickly as total daily irradiance increase to from 6.4 to

Continued on page 6

Table 1. Lighting classification of different seed-propagated bedding plant species with respect to flowering. Ambient daylight varied from 6.4 – 13.9 moles of light per day. Total light varied from 6.4 – 29.2 moles of light per day.

Facultative Irradiance Response	**Irradiance Indifferent Response**
Antirrhinum majus (Snapdragon)	*Anethum graveolens 'Mammoth'* (Dill)
Centranthus macrosiphon (Long-Spurred Valerian)	*Calendula officinalis* 'Calypso Orange' (Calendula)
Cleome hasslerana 'Rose Queen' (Cleome)	*Carpanthea pomeridiana* 'Golden Carpet'
Hibiscus moscheutos (Rose Mallow; Swamp Mallow)	*Celosia plumose* 'Flamingo Feather Purple' (Plumed Celosia)
Lavatera trimestris 'Silver Cup' (Lavatera)	*Cosmos bipinnatus* 'Diablo' (Cosmos)
Linaria maroccana (Toadflax)	*Dianthus chinensis* 'Ideal Cherry Picotee' (Dianthus)
Salvia farinacea 'Strata' (Blue Salvia)	*Dimorphotheca sinuata* 'Mixed Colors' (African Daisy)
	Gomphrena globosa 'Bicolor Rose' (Globe Amarath)
	Helianthus annus 'Vanilla Ice' (Sunflower)
	Helipterum roseum (Strawflower)
	Ipomea x multifida 'Scarlet' (Cardinal Climber)
	Legulosa speculum-veneris (Venus's Looking Glass)
	Leptosiphon hybrida
	Lobelia erinus 'Crystal Palace' (Lobelia)
	Mimulus x hybridus 'Magic' (Monkeyflower)
	Mirabilis jalapa (Four O'Clock)
	Nemophila menziesii (Baby Blue Eyes)
	Nigella damascene 'Miss Jekyll' (Love-In-The-Mist)
	Polemonium viscosum
	Verbascum phoeniceum (Mullein)
	Viguiera multiflora
	Zinnia elegans 'Exquisite Pink' and 'Peter Pan Scarlet' (Zinnia)

Continued from page 5

29.2 moles per day within their prescribed photoperiod.

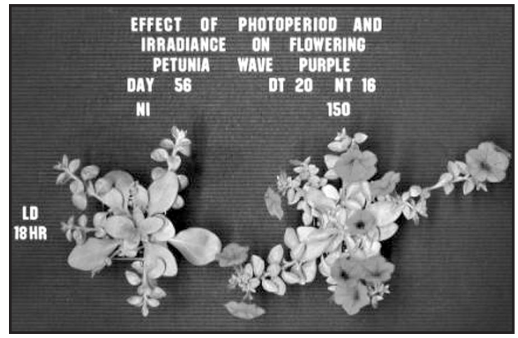

Figure 1. Effect of delivering long day conditions to Petunia x hybrida 'Purple Wave' flowering as a traditional night interruption (left) (2 *u*mol m^{-2} s^{-1} (10 footcandles); 10 pm to 2 am)) or as a day extension with high pressure sodium supplemental lighting (right). Light integrals for each treatment were 11.4-12.4 (left) and 24.4-25.4 (right) moles per day.

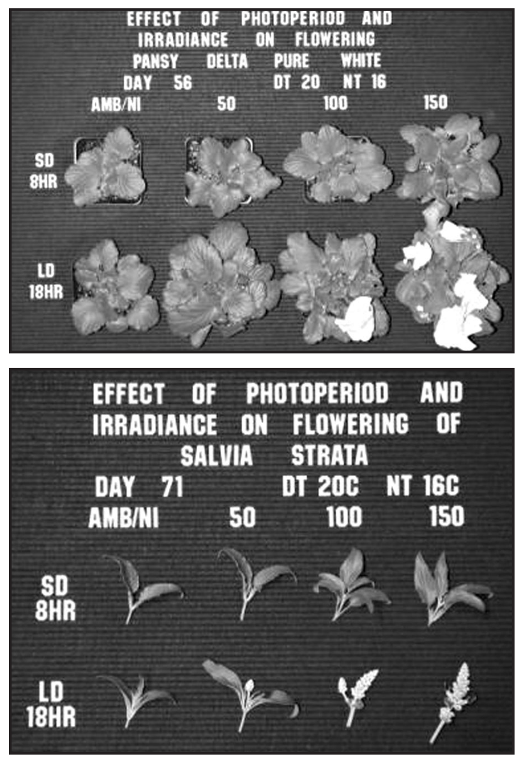

Figure 2a and b. The effect of photoperiod (long day (LD) and short day (SD)) and increasing light intensity (irradiance) on the facultative long-day plants Viola x wittrockiana 'Delta Pure White' (top) and Salvia farinacea 'Strata' (bottom) flowering

Continued on page 7

Continued from page 6

Irradiance levels were ambient daylight, or ambient plus 50, 100 or 150 *u*mol m^{-2} s^{-1}. Daily light integrals varied from 6.4 – 20.2 moles per day in these treatments.

Supplemental Lighting Effects on Plant Growth:

Although some plants may not flower earlier when supplemental lighting is provided, there are distinct benefits to crop quality such as increased plant mass and/or decreased plant height that are beneficial to a grower. High plant mass and short plants are usually associated with an increased plant quality. Internode elongation generally decreases as light intensity increases up to approximately 400 *u*mol m^{-2} s^{-1} or 2000 footcandles (unpublished data). In general, plant mass increases as light intensity, irradiance, increases. However, there is a maximum light intensity that plants can utilize. Further increasing light intensity (irradiance) above this maximum will not increase photosynthesis and plant mass further. For instance, Figure 3 shows plant photosynthetic rate versus light intensity of pansy, New Guinea impatiens and raspberry. Note that for each species there is a maximum photosynthetic rate and that increasing irradiance does not further increase photosynthesis and offers no benefit! For instance, a maximum photosynthetic rate is achieved on raspberry, New Guinea impatiens and pansy with irradiance levels of 500, 570 and 630 *u*mol m^{-2} s^{-1}, respectively.

Also note that the benefit of increasing irradiance with each crop differs from a standpoint of net photosynthesis. For instance, increasing light intensity from 200 to 300 *u*mol m^{-2} s^{-1} results in a net 20%, 20% and 33% increase in photosynthesis for raspberry, New Guinea impatiens, and pansy, respectively (Figure 3). In other words, plant mass increased most when irradiance increase from 200 to 300 *u*mol m^{-2} s^{-1} on pansy compared to raspberry and New Guinea impatiens.

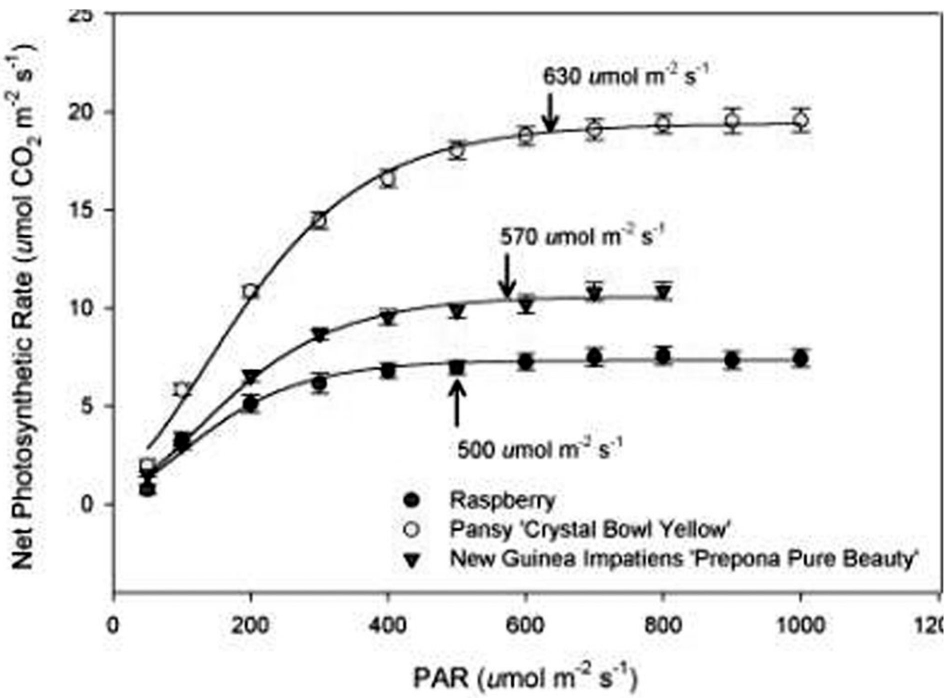

Fig. 1. The maximum rate of photosynthesis is often around 600 µmol m^{-2} s^{-1} (3000 footcandles) or less. The species were all grown at 68 ºF.

Supplemental lighting controls should be based on irradiance at plant level. On many sunny days lights can be shut off because irradiance levels exceed what the plant can use. Lighting above the level where photosynthesis is maximized wastes money and adds heat to the greenhouse! The only way to increase photosynthesis above the maximum rate reported is to increase carbon dioxide concentrations (CO_2) above ambient air levels (approximately 333 ppm). CO_2 levels less than ambient air levels are possible in a greenhouse as well and can limit crop photosynthesis. For instance, CO_2 levels within canopies can often drop below ambient levels and can limit photosynthesis. Further, when air is not circulated in a greenhouse photosynthesis levels can also be decreased through pockets of lower CO_2 concentrations.

How Does Heat Stress Affect Photosynthesis?

Stresses will reduce the maximum rate of photosynthesis (Figure 4). Water or high temperature stress can reduce photosynthesis. Water stress will result in the pores on the leaf (stomata) closing which limits photosynthesis by reducing CO_2 intake. This is the reason why regularly water stressed plants are smaller in size and/or mass than plants grown under non-water stressed conditions. Similarly, plants exposed to a short term high temperature stress also have a reduced capacity for photosynthesis (Figure 4).

Results of Supplemental Lights Will Vary Throughout North America:

The benefit of adding supplemental lighting for earliness of

Continued on page 8

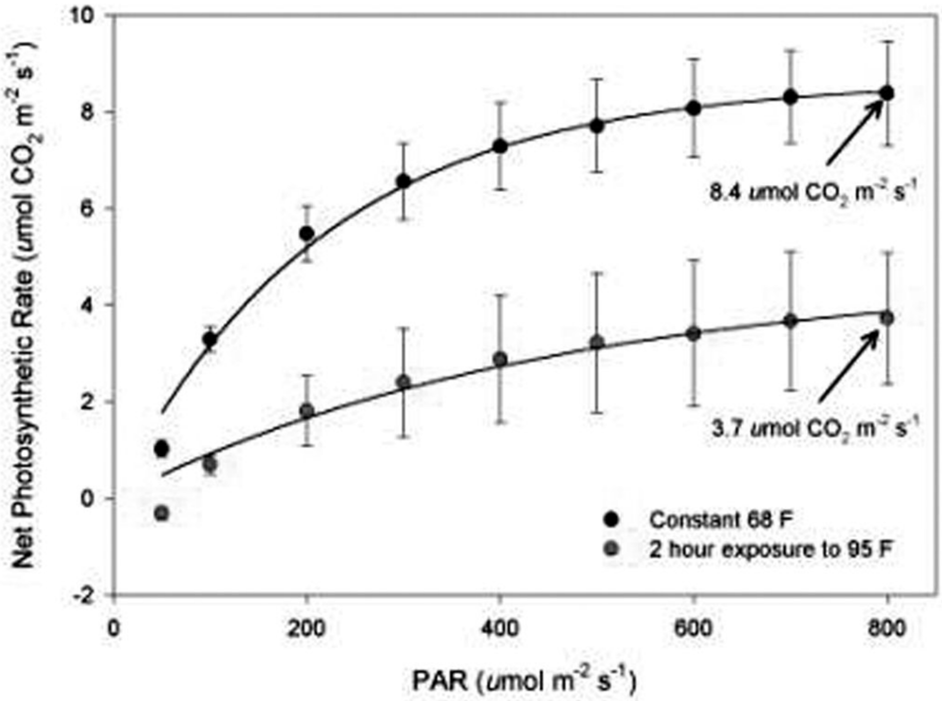

Fig. 2. A two-hour exposure to 95 ºF dramatically reduced photosynthetic rate of New Guinea Impatiens 'Celebration Orange'. Data presented above are photosynthetic rates measured the following day

Conclusions:

Supplemental lighting will decrease flowering time on facultative irradiance plants but not irradiance indifferent plants. If a grower's focus is decreased internode length, internode length will decrease as light intensity or irradiance increases up to approximately 400 *u*mol m^{-2} s^{-1} (2000-2250 footcandles). If increasing plant mass or photosynthesis is your objective to increase plant quality, increasing irradiance over 650 *u*mol m^{-2} s^{-1} will likely have no effect on photosynthesis on many crops. Periodic stresses (water and heat) will decrease the ability of a plant to do photosynthesis and therefore waste any investment you may have in providing supplemental lighting.

Continued from page 7

flowering and increased photosynthesis varies with geographic location. Our data are based on adding supplemental lighting to ambient daylight conditions in Minnesota. Ambient daily light integral ranged from 6.4 to 13.9 moles day^{-1}. Supplemental lighting resulted in a variation in actual daily light integrals ranging from 6.4 to 29.2 moles per day. Supplemental lighting will have a greater effect on flowering time on crops with a facultative irradiance response in lower light areas of the country than Minneapolis/St.Paul such as western Michigan, western New York, and/or the Seattle area. In contrast, adding supplemental lighting in higher light areas of the country than Minneapolis/St. Paul such as Atlanta and Miami may have little or no effect on hastening flowering developmentally and/or photosynthetic rate because the plants may already be receiving sufficient light.

Table 2. Variation in total daily light available for plant growth outside of the greenhouse.

		MONTH			
City		**January**	**April**	**July**	**October**
Seattle	Outside	5-10	25-30	40-45	15-20
	Inside	3-6	15-18	24-27	9-12
Minneapolis	Outside	10-15	30-35	40-45	15-20
	Inside	3-9	18-21	24-27	9-12
Atlanta	Outside	15-20	35-40	40-45	25-30
	Inside	9-12	21-24	24-27	15-18
Miami	Outside	20-25	40-45	40-45	35-40
	Inside	12-15	24-27	24-27	21-24

Numbers based on a FIRST research report: Light management in greenhouses. I. Daily light integral: A useful tool for the U.S. Floriculture industry. By James Faust, Clemson University. Inside values were calculated by taking 60% of the outside levels which is standard for a double polyhouse.