Temperature and Daily Light Integral Effects on Crop Timing and Quality of Bedding Plants

Matthew G. Blanchard and Erik S. Runkle
Department of Horticulture, Michigan State University

Introduction and Objective

The cost of energy for greenhouse heating has increased by 30 to 50% since 2004. The increase and fluctuations in fuel prices has threatened the profitability of the greenhouse industry and has put greenhouses and nurseries in the north at a competitive disadvantage to growers in the mid-South. One strategy to cope with higher energy prices is to produce greenhouse crops in a more energy-efficient environment.

Figure 1. Experimental setup with low and high DLI treatments on left and right, respectively.

The goal of this study is to generate species-specific information on how temperature and daily light integral influence plant development and crop timing for several species of bedding plants. The data collected from these experiments will be used to develop mathematical crop models that predict the effect of changing greenhouse temperature and daily light integral on time to flower and plant quality.

Experimental Protocol

- 19 species of seed propagated bedding plants were investigated during Year 1 (Table 1).
- 10 additional species of seed propagated bedding plants are currently being investigated (Table 2).
- Seeds of each species were sown in 288-cell plug trays by Raker and Sons, Inc. and were subsequently grown in controlled temperature chambers at 68 °F (20 °C) and under an average daily light integral (DLI) of 10 to 11 $mol \cdot m^{-2} \cdot d^{-1}$. After seedlings of each species were ready for transplant (≈3 to 4 weeks after seed sow), plants were transplanted into 4-inch (10-cm) round pots and grown in glass-glazed greenhouses with four different temperature set points and two DLIs (Figure 1).

Treatments

- Plant species with a *low* base temperature were grown at a constant 57, 63, 68, or 73 °F (14, 17, 20, and 23 °C).
- Plant species with a *high* base temperature were grown at a constant 63, 68, 73 or 79 °F (17, 20, 23, and 26 °C).
- 2 DLIs at each temperature were provided by a combination of shade curtains and different light intensities from high-pressure sodium (HPS) lamps. The average DLIs during the first and second replications ranged from 5 to 20 $mol \cdot m^{-2} \cdot d^{-1}$.
- The 16-h photoperiod (0600 to 2200 HR) consisted of natural photoperiods with day-extension lighting from HPS lamps.
- A vapor-pressure deficit of 1.2 kPa maintained during the night.

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Greenhouse Environment

- Air temperature and light intensity were closely monitored and recorded in all growing environments using thermocouples and line quantum sensors connected to a CR10 data logger and data were recorded every 10 s. Plant data were analyzed using the calculated average daily air temperature and DLI for each plant from transplant to the date of flowering.

Data Collection and Analysis

- The date of first open flower was recorded and time to flower was calculated for each plant. When each plant flowered, the number of nodes on the primary shoot, plant height, and number of flowers and flower buds were recorded.
- Data were analyzed using a statistical analysis software and response surface regression was performed on data to determine the significance of DLI and temperature on each of the variables studied for each species. Regression analysis was performed on the data to determine the model coefficients. The equations used in the predictive models are in the form:

$$y = y_0 + aT + bT^2 + cDLI + dDLI^2 + eT \times DLI$$

- Data analysis has been performed on four species and additional species are currently being analyzed.

Table 1. Bedding plant species that were included in Year 1 of the temperature and DLI experiments.

1. *Ageratum houstonianum* (Ageratum)^z	11. *Pelargonium ×hortorum* (Seed geranium)^y
2. *Antirrhinum majus* (Snapdragon)^z	12. *Petunia multiflora* (Petunia Easy Wave)^z
3. *Begonia ×semperflorens* (Fibrous begonia)^y	13. *Portulaca oleracea* (Portulaca)^y
4. *Catharanthus roseus* (Vinca)^y	14. *Rudbeckia hirta* (Rudbeckia)^z
5. *Cosmos sulphureus* (Cosmos)^z	15. *Salvia farinacea* (Blue salvia)^y
6. *Dianthus chinensis* (Dianthus)^z	16. *Tagetes erecta* (African marigold)^z
7. *Gazania rigens* (Gazania)^y	17. *Verbena ×hybrida* (Verbena)^y
8. *Lobelia erinus* (Lobelia)^z	18. *Viola cornuta* (Pansy)^z
9. *Lobularia maritima* (Alyssum)^z	19. *Zinnia elegans* (Zinnia)^y
10. *Lycopersicon esculentum* (Tomato)^y	

^{z}Grown at 57, 63, 68, or 73 °F
^{y}Grown at 63, 68, 73 or 79 °F

Table 2. Bedding plant species that are currently being investigated in Year 2 of the temperature and DLI experiments. All species are being grown at 57, 63, 68, 73, or 79 °F.

1. *Browallia speciosa* (Browallia)	6. *Pentas lanceolata* (Pentas)
2. *Cleome sp.* (Cleome)	7. *Senecio cineraria* (Dusty Miller)
3. *Cosmos bipinnatus* (Cosmos)	8. *Petunia grandiflora* (Petunia)
4. *Dahlia* (Dahlia)	9. *Petunia milliflora* (Petunia)
5. *Osteospermum sp.* (Osteospermum)	10. *Tagetes patula* (French marigold)

Results

Petunia Easy Wave ‘Coral Pink’

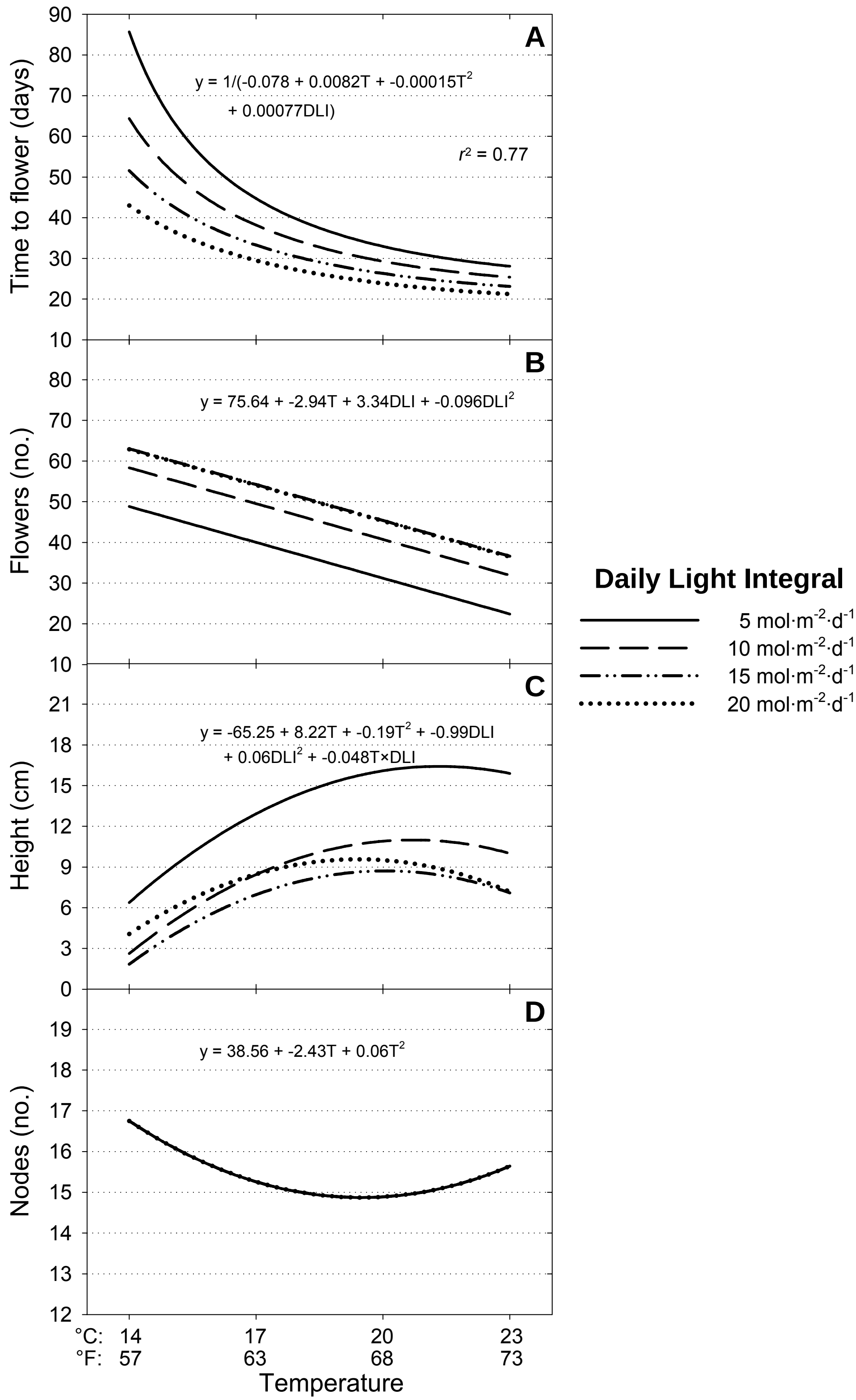

Figure 3. The effect of temperature and daily light integral on time to flower (**A**), number of flower buds (**B**), height at flowering (**C**), and number of nodes below the first open flower (**D**) in *Petunia* Easy Wave ‘Coral Pink’.

Petunia Easy Wave 'Coral Pink'

38 days from transplant at (°F):

57	63	68	73

Predicted days to flower from transplant

57	63	68	73
86	45	33	28

Predicted flower bud number

57	63	68	73
49	40	31	22

Predicted days to flower from transplant

57	63	68	73
56	35	27	24

Predicted flower bud number

57	63	68	73
62	53	44	35

Figure 4. The predicted time to flower from a 288-cell plug and the number of flowers in *Petunia* Easy Wave 'Coral Pink' grown at 57, 63, 68, or 73 °F and under an average daily light integral of 5 or 13 mol·m^{-2}·d^{-1}. The coefficients for the models are presented in Figures 3A and 3B.

Results

- Temperature and DLI both influenced time to flower; as temperature and DLI increased, time to flower decreased (Figure 3A). The predicted time to flower in plants grown under an average DLI of 13 mol·m^{-2}·d^{-1} decreased from 56 to 24 days as temperature increased from 57 to 73 °F (Figure 4). The flowering time model accurately predicted time to flower within ± 5 days and ± 7 days for 69% and 79% of the data set, respectively.
- The number of flower buds decreased as temperature increased and DLI decreased (Figure 3B). In plants grown under an average DLI of 13 mol·m^{-2}·d^{-1}, the predicted flower number decreased by 27 as temperature increased from 57 to 73 °F. The saturation DLI for maximum flower bud number was 18 mol·m^{-2}·d^{-1}.
- Plant height at flower increased as temperature increased (Figure 3C). Plants grown under a DLI of 5 mol·m^{-2}·d^{-1} and at 70 °F were the tallest (16.4 cm).
- The number of nodes was influenced by temperature, but not DLI (Figure 3D). As temperature increased from 57 to 68 °F, node number at flower decreased by 2.

Verbena 'Obsession Lilac New'

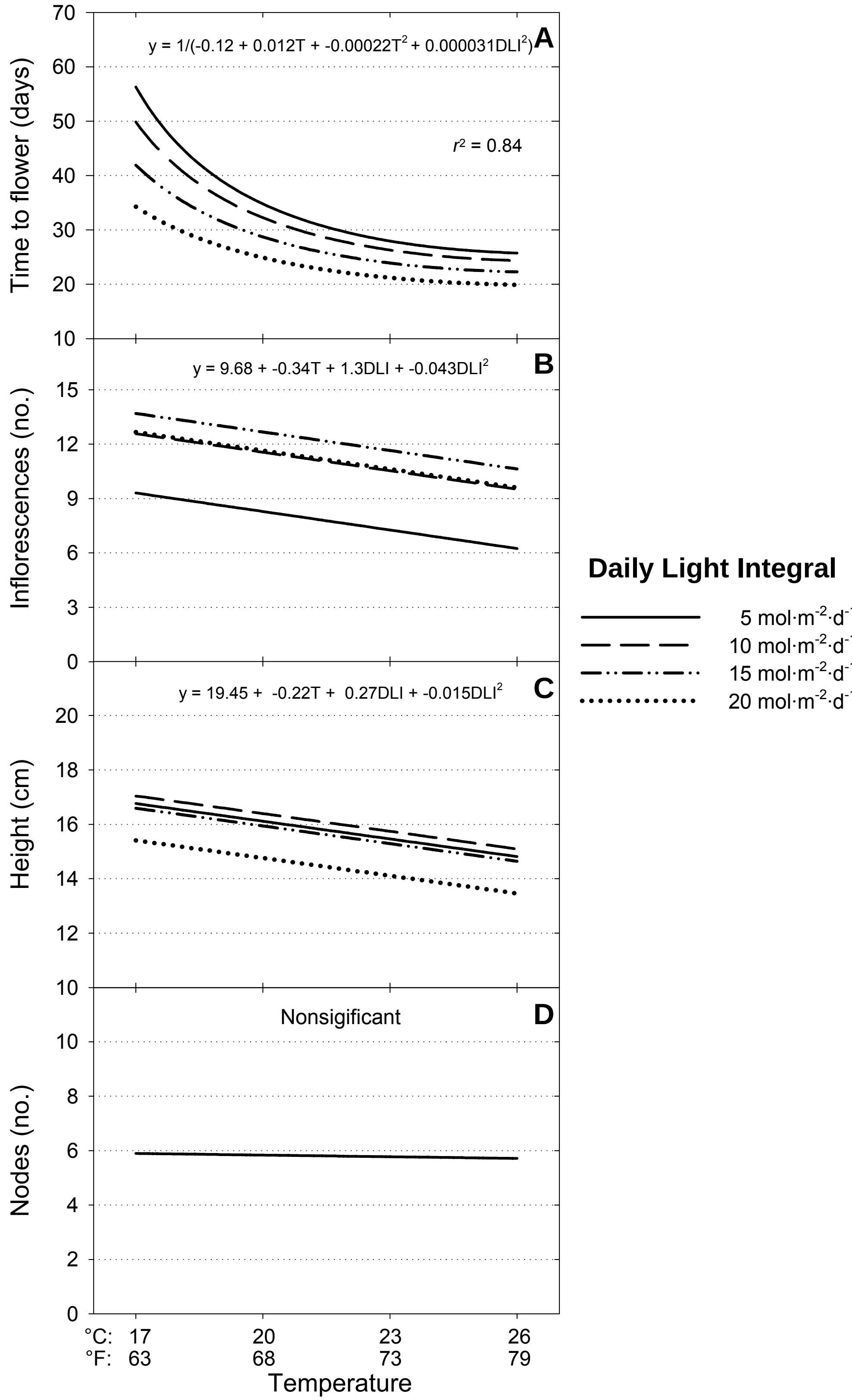

Figure 5. The effect of temperature and daily light integral on time to flower (**A**), number of inflorescences (**B**), height at flowering (**C**), and number of nodes below the first open flower (**D**) in *Verbena* 'Obsession Lilac New'.

Verbena ‘Obsession Lilac New’

37 days from transplant at (°F):

63	**68**	**73**	**79**

Predicted days to flower from transplant

63	68	73	79
56	35	28	26

Predicted inflorescence number

63	68	73	79
9	8	7	6

Predicted days to flower from transplant

63	68	73	79
45	30	25	23

Predicted inflorescence number

63	68	73	79
14	13	12	10

Figure 6. The predicted time to flower from a 288-cell plug and the number of flowers in *Verbena* ‘Obsession Lilac New’ grown at 63, 68, 73, or 79 °F and under an average daily light integral of 5 or 13 mol·m^{-2}·d^{-1}. The coefficients for the models are presented in Figures 5A and 5B.

Results

- Temperature and DLI both had a significant effect on time to flower; as temperature and DLI increased, time to flower decreased (Figure 5A). The predicted time to flower in plants grown under an average DLI of 13 mol·m^{-2}·d^{-1} decreased from 45 to 23 days as temperature increased from 63 to 79 °F (Figure 6). The flowering time model accurately predicted time to flower within ± 5 days and ± 7 days for 82% and 91% of the data set, respectively.
- The number of inflorescences decreased as temperature increased from 63 to 79 °F and as DLI decreased from 16 to 5 mol·m^{-2}·d^{-1} (Figure 5B). The predicted inflorescence number for plants grown under an average DLI of 13 mol·m^{-2}·d^{-1} decreased from 14 to 10 as temperature increased from 63 to 79 °F (Figure 6).
- Plant height at flower decreased as temperature and DLI increased (Figure 5C). The shortest plants (13.5 cm) were grown at 79 °F and under a DLI of 20 mol·m^{-2}·d^{-1}.
- Temperature and DLI did not significantly influence the number of nodes at first flower (Figure 5D).

Cosmos sulphureus ‘Cosmic Orange’

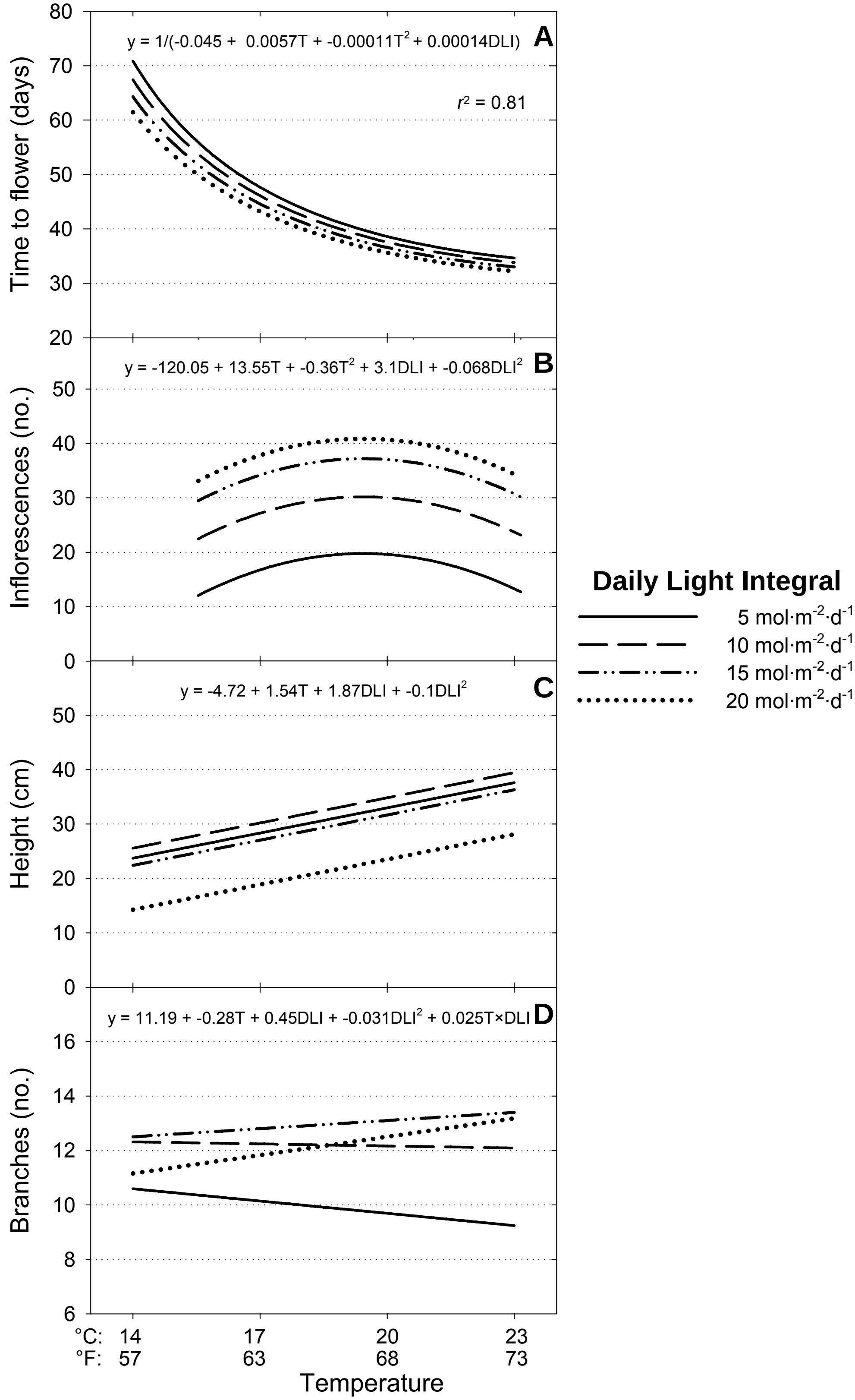

Figure 7. The effect of temperature and daily light integral on time to flower (**A**), number of inflorescences (**B**), height at flowering (**C**), and number of branches (**D**) in *Cosmos sulphureus* ‘Cosmic Orange’.

Cosmos sulphureus ‘Cosmic Orange’

44 days from transplant at (°F):

57 63 68 73

Mean DLI

5 mol·m^{-2}·d^{-1}

Predicted days to flower from transplant

57	63	68	73
71	48	39	35

Predicted inflorescence number

57	63	68	73
12	19	19	13

Mean DLI

13 mol·m^{-2}·d^{-1}

Predicted days to flower from transplant

57	63	68	73
66	45	37	33

Predicted inflorescence number

57	63	68	73
27	34	34	28

Figure 8. The predicted time to flower from a 288-cell plug and the number of inflorescences in *Cosmos sulphureus* ‘Cosmic Orange’ grown at 57, 63, 68, or 73 °F and under an average daily light integral of 5 or 13 mol·m^{-2}·d^{-1}. The coefficients for the models are presented in Figures 7A and 7B.

Results

- Temperature and DLI both influenced time to flower; as temperature and DLI increased, time to flower decreased (Figure 7A). The predicted time to flower in plants grown under an average DLI of 13 mol·m^{-2}·d^{-1} decreased from 66 to 33 days as temperature increased from 57 to 73 °F (Figure 8). The flowering time model accurately predicted time to flower within ± 5 days and ± 7 days for 85% and 93% of the data set, respectively.
- Inflorescence number increased as temperature increased from 57 to 66 °F and as DLI increased from 5 to 20 mol·m^{-2}·d^{-1} (Figure 7B). Inflorescence number was maximal at 66 °F. The predicted inflorescence number for plants grown at 68 °F increased from 19 to 34 as the average DLI increased from 5 to 13 mol·m^{-2}·d^{-1} (Figure 8).
- Plant height at flower increased as temperature and DLI increased (Figure 7C). The tallest plants (37.6 cm) were grown at 57 °F and under a DLI of 5 mol·m^{-2}·d^{-1}.
- Temperature and DLI interacted to influence the number of branches (Figure 7D). In plants grown under a DLI of 15 to 20 mol·m^{-2}·d^{-1}, branch number increased as temperature increased.

Estimating Energy Use

- Another objective of this research project is to identify the growing temperature that consumes the least amount of energy for each finish crop. Over the next year, our data on crop timing and plant quality will be integrated into Virtual Grower, which is a computer program created by Jonathan Frantz and colleagues of the USDA-ARS Greenhouse Production Group in Toledo, Ohio.
- This interactive decision-support tool will provide greenhouse growers with information on crop timing and predicted energy consumption and cost based on greenhouse location and structure, heating set points, time of year, fuel type, fuel cost, and other user inputs.
- Virtual Grower can be downloaded for free at: www.ars.usda.gov/services/software/download.htm?softwareid=108.

Results

- Table 3 provides an example of the predicted greenhouse heating costs per ft^2 in Grand Rapids, MI and Charlotte, N.C. using flowering time data for verbena and the Virtual Grower software.
- To finish verbena from a 288-cell plug tray in Grand Rapids, MI on March 15, April 15, or May 15, a mean daily temperature of 73 °F is predicted to consume the least amount of energy for greenhouse heating (Table 3).
- In Charlotte, N.C., the production temperature that is the most energy efficient for a finish date of March 15 and April 15 is predicted to be 73 °F and 68 °F, respectively. For a finish date of May 15, a mean daily temperature of 68 or 73 °F were both identified as the most energy efficient production temperatures (Table 3).

Table 3. The effects of finish date and mean daily temperature on time to first flower in verbena and the predicted greenhouse heating cost in Grand Rapids, MI and Charlotte, N.C. Time to flower is from a 288-cell plug tray grown under a 16-h photoperiod and under a daily light integral of 15 mol·m^{-2}·d^{-1} and was calculated using the equation: days to flower = 1/(-0.12 + 0.012T + -0.00022T^2 + 0.000031DLI^2).

Finish date	Mean daily temperature (°F)	Time to flower (days)	Heating cost per ft^2 ($/crop)^z		Heat savings compared to 57 °F	
			Grand Rapids, MI	*Charlotte, N.C.*	*Grand Rapids, MI*	*Charlotte, N.C.*
March 15	63	42	$0.61	$0.32	--	--
	68	29	$0.44	$0.23	27.9%	28.1%
	73	24	$0.41	$0.22	**32.8%**	**31.3%**
	79	22	$0.45	$0.26	26.2%	18.8%
April 15	63	42	$0.39	$0.18	--	--
	68	29	$0.30	$0.14	23.1%	**22.2%**
	73	24	$0.27	$0.15	**30.8%**	16.7%
	79	22	$0.31	$0.18	20.5%	0.0%
May 15	63	42	$0.23	$0.09	--	--
	68	29	$0.18	$0.08	21.7%	**11.1%**
	73	24	$0.17	$0.08	**26.1%**	**11.1%**
	79	22	$0.20	$0.11	13.0%	-18.2%

^{z}Heating costs were calculated using the Virtual Grower software with the following greenhouse characteristics: five spans each 75- by 25-feet, north-south orientation of average construction, double-poly glazing with arched roof, 3-foot insulated concrete knee wall, 9-foot gutter, 12-foot peak height, 55 percent energy-efficient heater, no curtain system and natural gas at $1.20/therm.