Energy-Efficient Annuals

Timing Marigolds

In part three of a 12-part series, researchers from Michigan State University present research-based information for scheduling annuals in a more energy-efficient and predictive manner.

by ***MATTHEW BLANCHARD*** and ***ERIK RUNKLE***

IN the first article of this scheduling annuals series, we introduced the concepts of temperature and daily light integral (DLI) and how these factors influence crop timing and plant quality. In the second article, Virtual Grower software was presented as a tool to predict energy costs for greenhouse heating. In this article, we present crop timing data for two species of marigolds, then estimate greenhouse heating costs to produce marigolds at different temperatures and in different locations.

Marigolds are among the top 10 bedding plants produced in the United States. In 2007, the 15 largest floriculture-producing states collectively sold 3.7 million flats at a total wholesale value of $31.7 million. Four species of marigolds are commonly grown commercially and include African or American marigold (*Tagetes erecta*), French marigold (*T. patula*), sweet-scented marigold (*T. lucida*), and signet marigold (*T. tenuifolia*). Our crop scheduling research focused on African and French marigolds.

Materials and Methods

Seeds of African marigold 'Antigua Primrose' and 'Moonstruck Orange' and French marigold 'Janie Flame' and 'Bonanza Yellow' were sown in 288-cell plug trays by C. Raker & Sons, then grown in controlled environmental growth chambers at Michigan State University at 68°F (20°C). The photoperiod was 16 hours and the DLI was 9 to 11 $mol \cdot m^{-2} \cdot d^{-1}$.

When plugs were ready for transplant (two to four weeks after seed sow, depending on variety), they were transplanted into 4-inch pots and grown in greenhouses with constant temperature set points of 57, 63, 68, 73 and 79°F (14, 17, 20, 23 and 26°C). At each temperature, plants were grown under a 16-hour photoperiod with two different DLIs provided by a combination of shade curtains and different light intensities from high-pressure sodium lamps.

The experiment was performed twice to obtain average DLIs that ranged from 3.5 to 21 $mol \cdot m^{-2} \cdot d^{-1}$. The flowering date was recorded for each plant when an inflorescence with at least 50 percent of the ray petals were fully reflexed. When each plant flowered, plant height, number of leaves and number of flowers and flower buds were recorded.

Crop timing data was used to develop mathematical models to predict

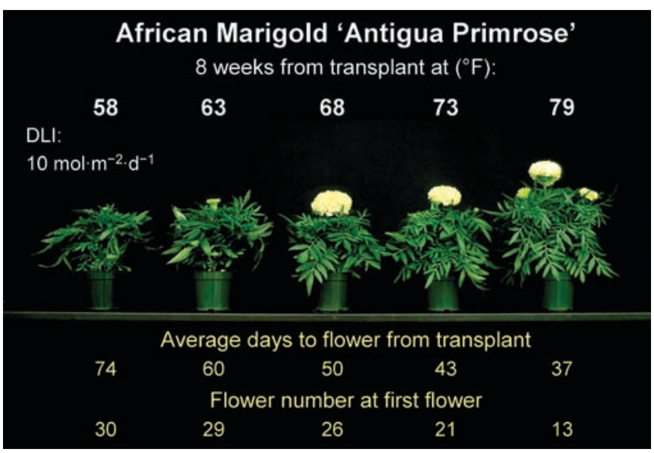

Figure 1. The effects of average daily temperature on time to flower and number of flower buds (at first flowering) in African marigold. Plants were grown under a 16-hour photoperiod and an average daily light integral of 10 $mol \cdot m^{-2} \cdot d^{-1}$. Photograph was taken eight weeks after transplant from a 288-cell plug tray.

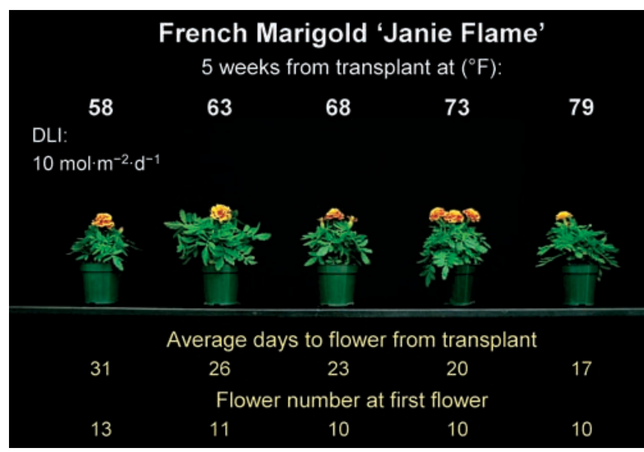

Figure 2. The effects of average daily temperature on time to flower and number of flower buds (at first flowering) in French marigold. Plants were grown under a 16-hour photoperiod and an average daily light integral of 10 $mol \cdot m^{-2} \cdot d^{-1}$. Photograph was taken five weeks after transplant from a 288-cell plug tray.

flowering time and plant quality under different temperature and DLI conditions. The scheduling models were validated by growing marigolds at three different constant temperatures to compare predicted flowering times with actual times. Temperature responses were similar between cultivars of African and French marigolds, so one crop timing model was used for each species. The Virtual Grower software (free at **www.virtualgrower.net**) was used to estimate the cost to heat a 21,504 square foot greenhouse (about half an acre) to produce a marigold crop for different finish dates and at different locations in the U.S.

Table 1. Date of transplant of 288-cell plug trays of African marigold 'Antigua Primrose' and French marigold 'Janie Flame' to achieve first flowering when grown at different temperatures for two market dates. Time to flower is presented in Figures 1 and 2. Plugs were grown at 68°F and under a 16-hour long day. A 16-hour long day and an average daily light integral of 10 mol·m^{-2}·d^{-1} were provided during the finish stage.

Market Date	Average Temperature	Date Of Transplant Of 288-Cell Plugs For Desired Market Dates	
		African Marigold	French Marigold
April 1	58°F	January 16	March 1
	63°F	January 31	March 5
	68°F	February 9	March 9
	73°F	February 16	March 12
May 15	58°F	March 1	April 14
	63°F	March 16	April 18
	68°F	March 25	April 22
	73°F	April 1	April 25

Table 2. Estimated heating costs to produce flowering African marigold 'Antigua Primrose' and French marigold 'Janie Flame' (from a 288-cell plug; see Table 1) at different temperatures and locations for first flowering on April 1 or May 15. Cities were chosen from each of the seven leading garden plant-producing states. Calculations performed with Virtual Grower 2.01 software with constant temperatures. Greenhouse characteristics include: eight spans each at 112 by 24 feet, arched 12-foot roof, 9-foot gutter, polyethylene double layer roof, polycarbonate bi-wall ends and sides, forced air unit heaters burning natural gas at $1 per therm ($10.24 MCF), 50 percent heater efficiency, no energy curtain and an hourly air infiltration rate of 1.0. (The lowest predicted energy cost is highlighted in green for each location and market date.)

Location	Estimated Heating Cost (U.S. Dollars Per Square Foot Per Crop)							
	April 1				May 15			
	58°F	63°F	68°F	73°F	58°F	63°F	68°F	73°F
	African Marigold							
San Francisco, Calif.	0.18	0.20	0.24	0.27	0.13	0.16	0.19	0.22
Tallahassee, Fla.	0.19	0.19	0.22	0.23	0.06	0.05	0.07	0.10
Grand Rapids, Mich.	0.69	0.65	0.60	0.58	0.36	0.32	0.30	0.31
New York, N.Y.	0.52	0.46	0.46	0.46	0.22	0.20	0.20	0.22
Charlotte, N.C.	0.32	0.31	0.29	0.28	0.12	0.12	0.13	0.16
Cleveland, Ohio	0.61	0.56	0.57	0.55	0.30	0.28	0.30	0.27
Fort Worth, Texas	0.19	0.20	0.22	0.23	0.05	0.06	0.07	0.10
	French Marigold							
San Francisco, Calif.	0.07	0.09	0.11	0.13	0.05	0.07	0.09	0.10
Tallahassee, Fla.	0.04	0.06	0.07	0.09	0.00	0.01	0.01	0.03
Grand Rapids, Mich.	0.22	0.22	0.23	0.24	0.09	0.09	0.10	0.11
New York, N.Y.	0.15	0.17	0.17	0.18	0.04	0.06	0.06	0.07
Charlotte, N.C.	0.08	0.10	0.12	0.12	0.03	0.03	0.03	0.05
Cleveland, Ohio	0.19	0.22	0.20	0.22	0.07	0.09	0.11	0.11
Fort Worth, Texas	0.04	0.06	0.07	0.08	0.00	0.01	0.02	0.04

Results

In both African and French marigolds, time to flower decreased as temperature and DLI increased. For example, under an average DLI of 10 mol·m^{-2}·d^{-1}, time to flower of African marigold decreased by 24 days as temperature increased from 58 to 68°F (**Figure 1**). French marigold grown under the same DLI flowered eight days earlier at 68°F compared to 58°F (**Figure 2**). This information can be used to determine the date 288-cell plugs need to be transplanted for two different market dates when grown at different temperatures (**Table 1**).

As the DLI increased from 4 to 16 mol·m^{-2}·d^{-1}, time to flower in African and French marigold grown at 63°F decreased by 10 and four days, respectively. The saturation DLI for the shortest time to flower was 12 mol·m^{-2}·d^{-1}. In other words, increasing the DLI above 12 mol·m^{-2}·d^{-1} did not shorten crop time.

In both species, the number of inflorescences decreased as temperature increased and as DLI decreased. For example, in African marigold grown under an average DLI of 10 mol·m^{-2}·d^{-1}, the number of flowers decreased by nine as temperature increased from 58 to 73°F.

Therefore, there is a trade-off between fast cropping and plant quality. African and French marigolds grown at the warmest temperature (79°F) and under the lowest DLI (4 mol·m^{-2}·d^{-1}) in our study were of poorest quality (e.g., few flowers and branches), whereas plants grown at 58°F and under 16 mol·m^{-2}·d^{-1} were of highest quality.

Heating Costs

The growing temperature that had the lowest predicted heating cost to produce a crop of African marigolds varied among locations and market dates (**Table 2**). For example, to produce a finish crop for April 1, a greenhouse located in San Francisco, Calif., would save 9 cents per square foot per crop in heating costs by growing at 58°F compared to 73°F.

In contrast, heating costs per square foot were 4 to 11 cents cheaper at four of seven locations when the crop was grown at 73°F versus 58°F. In other words, less energy was consumed by transplanting the African marigold crop later and growing warm compared to transplanting earlier and growing cool.

For French marigold, a production temperature of 58°F had the lowest predicted energy cost for both market dates at all locations. In every simulation, the heating cost to produce a crop of French marigolds was at least 50 percent cheaper than the heating costs for African marigolds because crop timing was so much shorter. The different responses of African and French marigold to temperature indicate that at many locations, it would be more energy efficient to grow these crops at different temperature set points.

The cost of energy for heating is just one of the many production expenses for greenhouse crops. Other factors, such as the number of crop turns and overhead costs, should also be considered when choosing the most economical growing temperature. **GG**

About the authors: Matthew Blanchard (**mgblanch@msu.edu**) is a Ph.D. candidate and Erik Runkle (**runkleer@msu.edu**) is associate professor and floriculture Extension specialist in the Department of Horticulture at Michigan State University.

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