$10.00

Control Plant Growth With Temperature

1. Understanding & Applying DIF

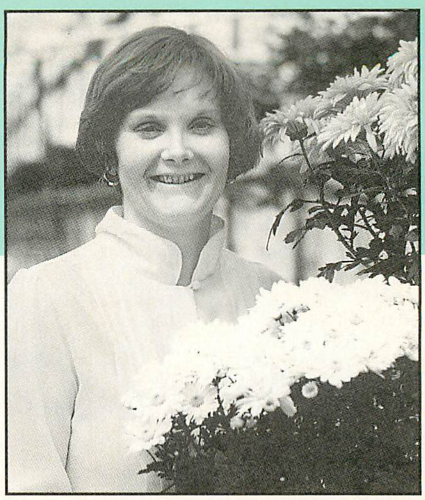
2. Growers on DIF

3. Choosing the Best Temperature for Growth & Flowering

4. Graphical Tracking

Reprinted from Greenhouse Grower

Spring 1990



"What's the dif?" is a slang phrase of a few years back. However, today, it has taken on a whole new meaning — one that's of particular importance to plant growers, thanks to trail-blazing research from Michigan State University.

DIF is a word coined by researchers at MSU to show the DIFference between day and night temperatures. The amount of the difference affects plant growth, as is pointed out in the accompanying articles reprinted from the February, March, April, and May issues of GREENHOUSE GROWER. Not only does DIF affect plant height, but average temperatures over a 24-hour period affect rate of plant development. For flowering, it may be day or night temperatures or both that are most critical.

These new concepts are revolutionizing production practices in the greenhouse. They are not easy to understand and are often confusing. That is why this booklet has been produced so that it can be used as a reference. For your convenience, there's also an index and a glossary of terms on the inside back cover.

Much more research remains to be done to determine critical temperatures for a much wider range of plant species. To help fund these efforts, half the money received from the sale of these booklets will go to floriculture research at MSU.

We are happy to bring you this booklet and hope it will make possible more uniform crops that flower precisely at the time you have scheduled.

Jane A. Lieberth

Jane A. Lieberth
Editor, GREENHOUSE GROWER

CONTENTS

Control Plant Growth With Temperature

Don't get behind on your crop or your competition. Adjusting day and night temperatures to control plant growth is revolutionizing production practices.

by DAVID L. KUACK

In the past most growers considered plant production to be an art rather than a science. They relied on experience to determine how they would manage a crop under varying weather conditions or for different flowering dates.

As we move into the '90s, however, the art of growing is quickly being eclipsed by the science of growing. The guesswork is being replaced by specific management practices based on the stages of plant development.

Dr. Will Carlson, Department of Horticulture, Michigan State University (MSU), believes today's growers, like their predecessors, are looking for very simple directions when it comes to crop production.

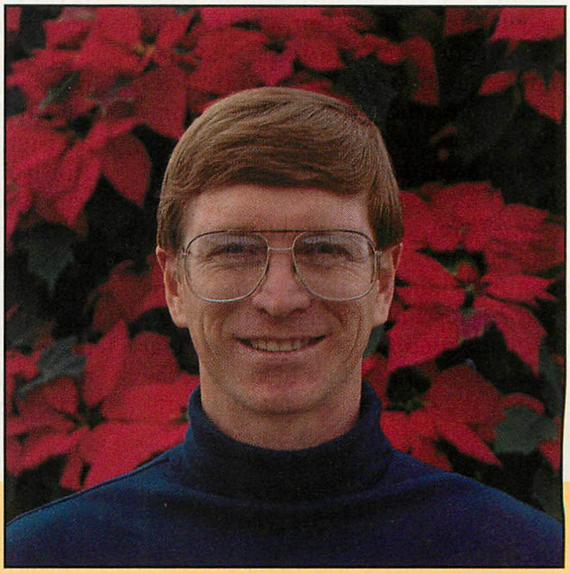
"Unfortunately, there are no simple recipes for growing," he says. "We are now asking growers to measure the stage of development of their crops and to tell us how they want their crops to look when they are finished. By measuring their plants twice a week and tracking the growth, growers now have the ability to accelerate or delay the rate of development to produce a specific size and flower number. We can provide growers with the necessary adjustments required to get plants to the right stage at the right time. This process is known as graphical tracking."

Researchers at MSU have found that temperature plays a critical role in regulating plant growth. Dr. Royal Heins, Department of Horticulture, MSU, explains that there is a direct relationship between the various stages of plant development (leaf unfolding, internode elongation, and flower initiation) and the temperatures to which plants are exposed.

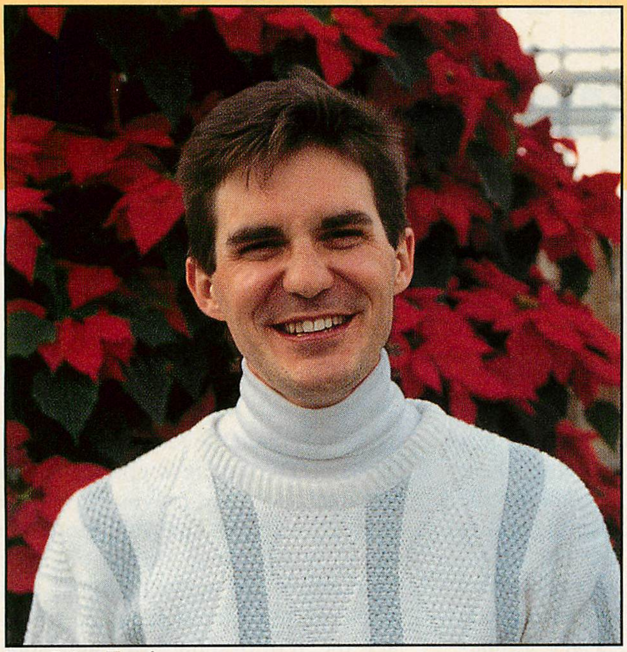
"A hierarchy exists for these stages of plant development," says Heins. "These stages change in importance as a plant moves through its production cycle. Growers need to be aware when these stages occur in their crops. As a plant grows, temperatures need to be adjusted to satisfy the requirements of each stage of development. If the proper temperatures are not provided, these stages can be delayed or accelerated, affecting the finishing time of a crop."

To better understand the relationship between temperature and plant development, we present this first of a series of articles that will examine the influence of temperature on leaf unfolding, internode elongation, and flower initiation. The series will provide growers with an explanation of the practical benefits and commercial application of using temperature to

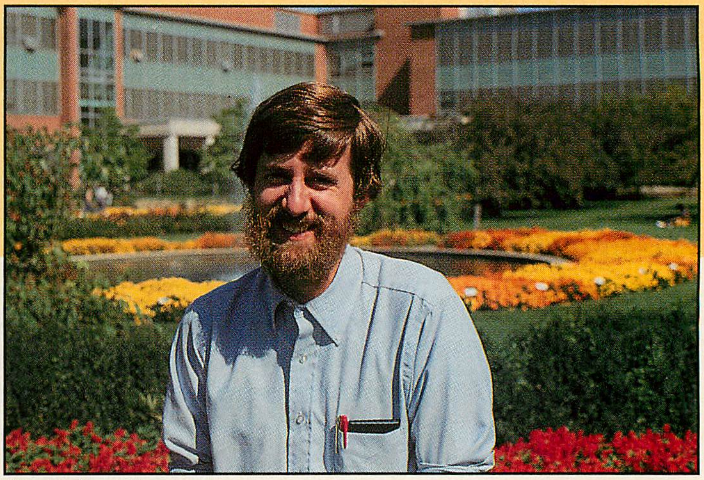
Dr. Royal Heins



Dr. Meriam Karlsson



Dr. John Erwin



Dr. Robert Berghage

control plant development. The first article will discuss the use of temperature to control plant height.

Starting With Research

The research related to controlling plant development was started at MSU by Heins and former graduate student Meriam Karlsson, who is now assistant professor, School of Agriculture and Land Resources Management, University of Alaska. The goal of their research was to create a model showing the effect of day and night temperature and light intensity on chrysanthemum development. Included in their studies were day/night combinations that had cooler nights than days. From research conducted in growth chambers, they observed that as the day temperature decreased, the final plant height also decreased.

Karlsson and Heins were able to validate their findings under greenhouse conditions by growing mums and Easter lilies using similar temperature conditions. They found that as the day temperature increased, the plants grew taller. As the day temperature decreased, the plants were shorter.

Former MSU graduate student John Erwin, who is now assistant professor, Department of Horticultural Science and Landscape Architecture, University of Minnesota, expanded these studies by increasing the number of day/night combinations. He found that when plants were grown under the same day/night temperature, regardless of the temperature, the plants finished at the same height. It was from these studies that the concept of DIF (the difference between day and night temperature) originated.

Seeking similar information about poinsettia growth, former graduate student Robert Berghage, who is now assistant professor, Department of Horticulture, New Mexico State University, developed a stem elongation model which showed how temperature controlled plant height.

The MSU research results have made it possible for growers to produce crops to meet specific requirements of height and number and size of flowers by a certain date. Although studies have been done with major flowering crops, additional research needs to be done to identify when specific stages of growth and flower initiation occur within other species. Also, the optimum temperatures for leaf unfolding, internode elongation, and flower initiation have yet to be determined for many species.

This new information is of immense practical interest to growers, many of whom are already successfully applying some of these findings. But there have been failures, too, simply because the concept of temperature control of plant development is not easy to understand.

There are different stages of plant development, and temperature affects these stages differently. Also, there are no recipes that work the same under all conditions. There is still much research yet to be done covering many other plant species.

The editors of GREENHOUSE GROWER are proud to present this series, which will be reprinted and made available as a booklet after the last article appears.

Articles to follow include:

- Practical experience of several growers who are using DIF to control plant height.
- Effect of temperature on leaf unfolding and flower initiation.
- Graphical tracking explained and growers' experience using this new production tool. **GG**

Understanding & Applying

DIF

Here's how to use this powerful production tool.

by ROYAL HEINS and JOHN ERWIN

THE height of a plant is determined by the number of its internodes and the length of these internodes. A plant grows faster as the average daily temperature increases. Therefore, increasing either the day or night temperature increases the number of internodes which mature in a given time period.

Day and night temperatures influence the final length of internodes in opposite ways. A discussion of these differences is the foundation of this article. In it, "plant height" is used interchangeably with "internode length." Statements made assume plants are at the same stage of development and have the same number of internodes.

Plant height increases as day temperature increases (see Figure 1). In contrast, plant height decreases as night temperature increases (see Figure 2). The increase in height due to an increase in day temperature or decrease in night temperature occurs over a wide range of temperatures.

The temperature range varies among species, depending on a plant's tolerance to low and high temperatures. The temperature range for "warm season" crops — including poinsettia and hibiscus — is 50° to 80°F. The temperature range for crops which tolerate low tempera-

Figure 1. Plant height increases as day temperature increases — here, from 14°C (57°F) to 30°C (86°F). Plants at warmer daily temperatures flowered before plants at cooler daily temperatures.

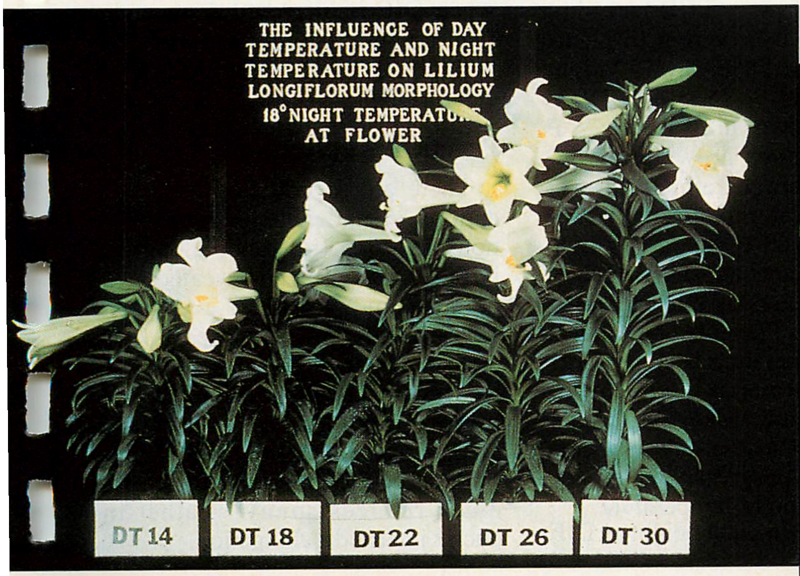
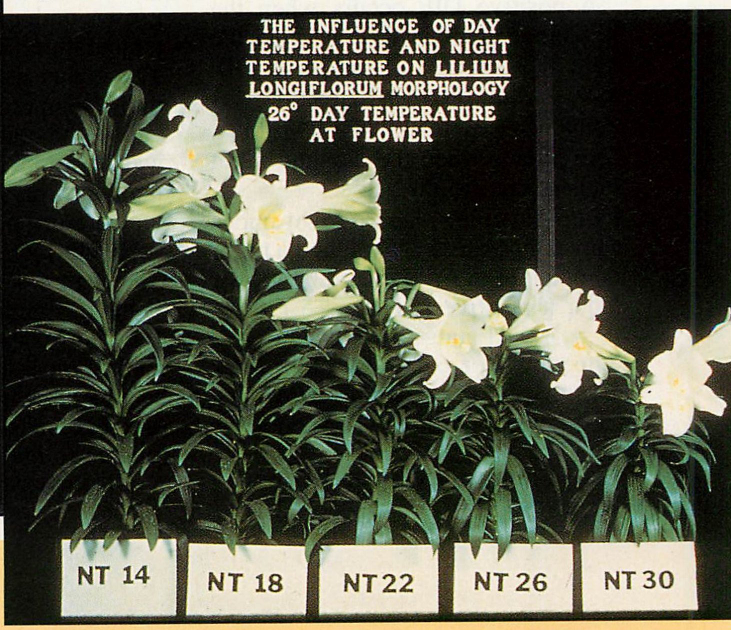


Figure 2. Plant height decreases as night temperature increases — here, from 14°C (57°F) to 30°C (86°F). Plants at warmer daily temperatures flowered before plants at cooler daily temperatures.



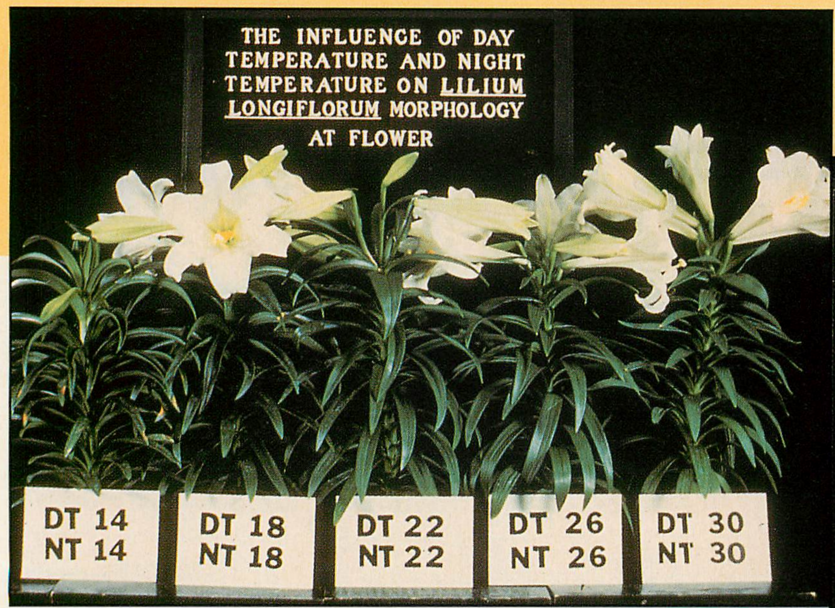


Figure 3. Plants grown under the same DIF have a similar height at flowering. Lilies here were grown under a −4°C DIF. Plants at warmer daily temperatures flowered before plants at cooler daily temperatures.

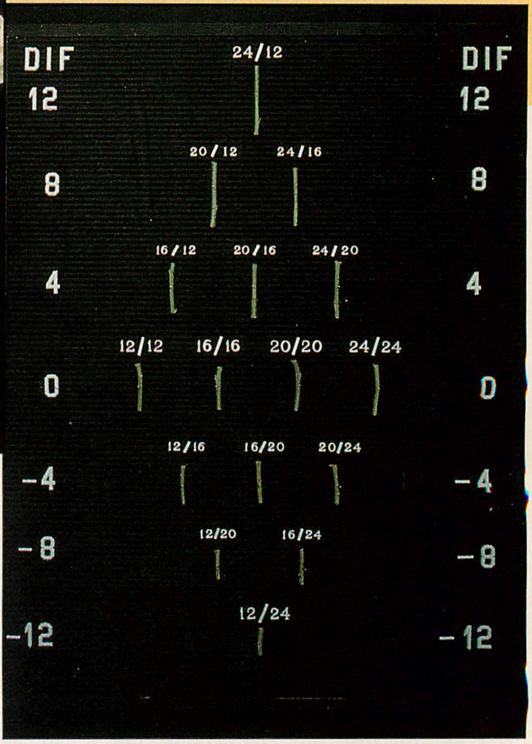


Figure 4. Internode length increases as DIF increases. Here, internodes are arranged in order of increasing DIF from −12°C DIF to +12°C DIF.

tures — including Easter lily, chrysanthemum, and petunia — is 40° to 80°F. The height of most plants decreases when temperatures exceed 80°F due to high temperature stress.

Defining DIF

From a grower's point of view, plant response to day and night temperatures can best be described by a relationship called DIF. DIF is defined as the mathematical DIF-ference between the day temperature (DT) and the night temperature (NT): DIF = DT − NT.

A positive DIF occurs when the day temperature is warmer than the night temperature. A negative DIF occurs when the day temperature is cooler than the night temperature. Zero DIF is when the day and night temperature are the same.

For example, plants grown under a day temperature of 70°F and a night temperature of 65°F would be grown under a positive DIF of +5 (70 − 65 = +5). Plants grown under a day temperature of 65°F and night temperature of 70°F would be grown under a negative DIF of −5 (65 − 70 = −5).

Plants grown under equal DIF values have a similar final height (see Figure 3). For example, plants grown under a 60°F day/65°F night temperature (60 − 65 = −5 DIF) are similar in height at flowering to plants grown under a 70°F day/75° night temperature (70 − 75 = −5 DIF). The plants grown at 70°F day/75°F night temperature grow faster because the average temperature is warmer, but internode lengths are similar to the 60°F day/65° F night temperature plants at flowering.

Height increases as DIF increases (see Figure 4). Plants become taller as the day temperature becomes progressively warmer relative to the night temperature. Likewise, plants become shorter as the day temperature becomes progressively cooler relative to the night temperature.

The increase in plant height as DIF increases is not the same over all values of DIF (see Figure 5). There is a greater increase in plant height when DIF is increased from a zero DIF to a positive DIF than when DIF is increased from a negative DIF to a zero DIF.

Practical Applications

There are several practical applications in understanding this relationship. First, internode elongation is faster during sunny weather than during cloudy weather, even if the average temperature does not increase, because sunny weather increases the day temperature, creating a more positive DIF. Increasing greenhouse ventilation and cooling so day temperatures don't increase as much reduces sunny weather-induced internode elongation.

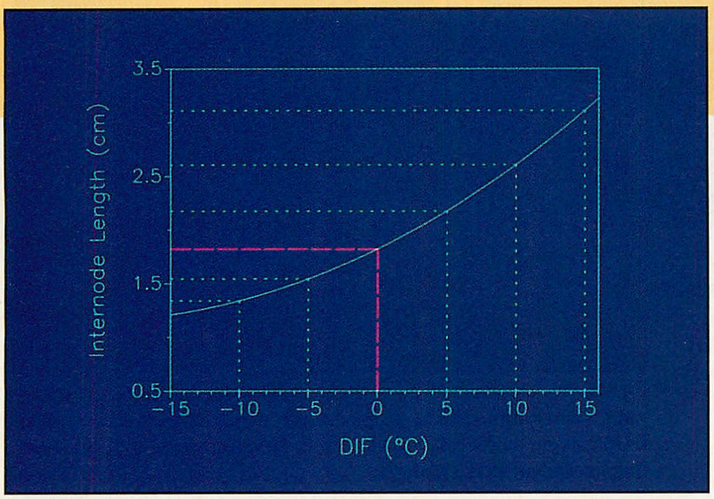


Figure 5. Plant height increases at an increasing rate as DIF increases. Shown here is effect of DIF on poinsettia internode length. The increase in internode length is less as DIF increases from −15 to 0 than from 0 to +15.

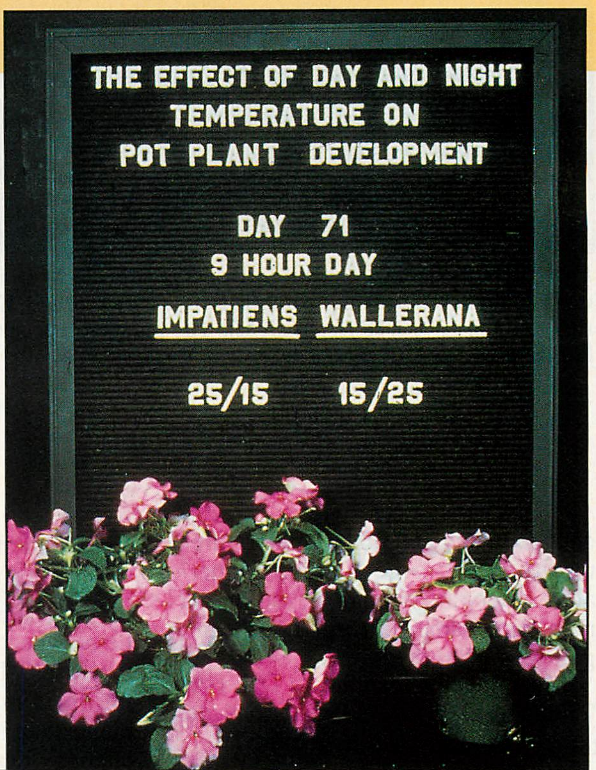


Figure 6. Many plants respond to DIF, including impatiens. The plant on the left was exposed to a +10°C DIF, and the plant on the right to a −10°C DIF.

Table 1. Response of plant species to DIF.

Large response	Small or no response	
Easter lily	Dianthus	Squash
Chrysanthemum	Tomato	Platycodon
Poinsettia	Snap Bean	French Marigold
Salvia	Watermelon	Tulip
Celosia	Sweet Corn	Hyacinth
Fuchsia	Gerbera	Narcissus
Impatiens	Asiatic lilies	Aster
Portulaca	Oriental lilies	
Hypoestes	Petunia	
Snapdragon	Geranium	
Rose		

Second, reducing the night temperature on plants which are growing tall under sunny weather and warm temperature conditions does not reduce internode elongation but promotes it. The traditional thought has been that lowering the night temperature on a rapidly growing crop "slows" development.

While lowering the night temperature slows plant development rate (maturation) because the average temperature is decreased, lowering the night temperature doesn't decrease, but increases internode elongation since DIF becomes more positive. Therefore, final height is greater at flowering.

Third, the amount of growth retardant necessary to control height decreases substantially when the day and night temperatures are maintained close together (zero DIF), when compared to growing plants with a large positive DIF. This is because a major reduction in internode elongation occurs when plants are grown with a zero DIF compared to a positive DIF.

Fourth, DIF can be used to promote internode elongation in circumstances when plants are shorter than desired. The best strategy to promote elongation on short plants is to lower the night temperature and raise the day temperature. For example, the height of short plants being grown at 65°F nights and 68°F days (68 − 65 = +3 DIF) can be increased by lowering the night temperature to 62°F and raising the day temperature to 72°F (72 − 62 = +10 DIF). If the

Figure 7. Chlorophyll content in plants is affected by DIF. Here, day and night temperature combinations ranged from +12°C DIF (left rear) to 12°C DIF (front right). The plants are progressively lighter green as DIF increases.

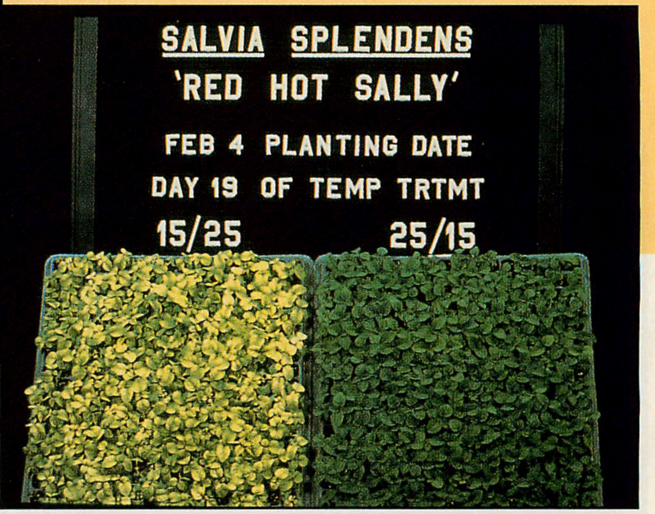


Figure 8. An excessive negative DIF is undesirable on many young seedlings. Salvia plugs on left were exposed to a −10°C DIF. Severe chlorosis slowed their development. Not all seedlings respond this strongly.

change in day and night temperatures results in the same average temperature afterwards, plant development rate is the same, but internode elongation is promoted.

Most species respond to DIF (see Table 1, Figure 6). Exceptions are tulip, narcissus, and hyacinth.

Chlorosis

Leaf color (chlorophyll content) is influenced by DIF. Leaves become lighter green and eventually chlorotic as DIF decreases from very positive to very negative (see Figure 7). This is not due to a nutrient deficiency.

Chlorosis at a particular negative DIF decreases as a leaf ages. Most chlorosis occurs on the youngest leaves and it can be reversed within a few days of placing plants in a positive DIF environment.

Severe chlorosis occurs in some species (see Figure 8), especially in young seedlings exposed to a very negative DIF (greater than −5 to −10). Young seedlings should not be exposed to a negative DIF large enough to cause chlorosis. Chlorosis, especially in seedlings, decreases photosynthesis and slows growth. Salvia and gerbera are especially sensitive to this.

Leaf Orientation

Leaf orientation in some plants is influenced by DIF (see Figure 9a, b). Leaves become more upright as DIF increases. The change in leaf orientation is more noticeable in some plants than in others. Leaf orientation changes dramatically in the Easter lily from very upright on positive DIF-grown plants to curving downward on negative DIF-grown plants. Lily leaves are nearly horizontal when DIF is zero.

Leaf orientation can be changed on an Easter lily until a leaf reaches maturity, which is about 20 to 25 days after it first becomes visible. This means non-mature, downward-curved leaves on a negative DIF-grown lily reorient and become more upright if the plant is placed under positive DIF conditions.

Rate of Response

The response to DIF is rapid (see Figure 10). Elongation, leaf orientation, and leaf chlorophyll content react on a daily basis to the DIF a plant is exposed to. This rapid reaction is both an asset and a liability when using DIF to control height.

It is an asset because internode elongation can be promoted or reduced on a daily basis. Internode elongation can be slowed immediately by reducing DIF. This asset can turn into a liability, however, when one wishes to suppress elongation but the weather conditions don't permit control of the day temperature. Bright, warm weather in the spring can cause rapid elongation, especially if plants have no growth retardant "built into" them.

Photoperiod Effect

The plant response to DIF is influenced by photoperiod (see Figure 11). Plants are shorter when grown under a negative DIF when days are eight hours long than when days are 12 hours long. Likewise, plants are taller under a positive DIF when days are 16 hours long than when days are eight hours long. In other words, plant response to DIF is greater under short days than long days.

Absolute response to DIF (inches of internode length) is greatest when internodes are elongating most rapidly (see Figure 12a, b, c). Plants do not elongate uniformly during development. For example, the lateral shoot of a pinched poinsettia or chry-

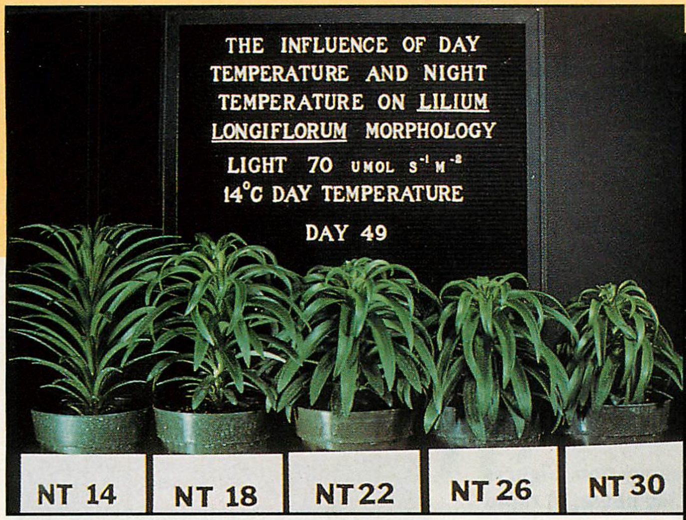


Figure 9a. Leaf orientation is influenced by DIF. Here, leaf orientation increases as DIF increases from −16°C DIF (plant on far right) to 0 (plant on far left).

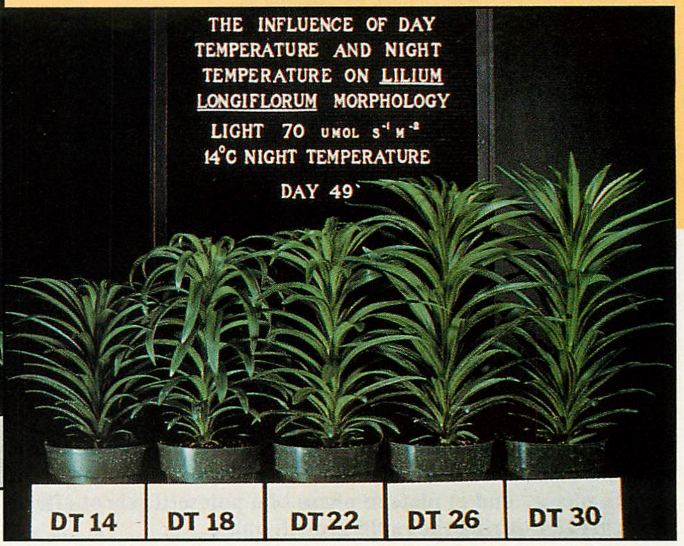


Figure 9b. Leaf orientation further increases as DIF increases from 0 (plant on far left) to +16°C DIF (plant on far right).

santhemum has three distinct phases.

Immediately after pinch, there is a lag phase of five to 10 days until lateral shoots start growing rapidly. The lateral shoots then enter a rapid growth phase after which growth again slows as the plant flowers.

The DIF a plant is exposed to during the lag phase and the flowering phase has only a minor impact on final internode length. The DIF during the rapid growth phase has a major influence on final height.

DIF Limitations

One cannot always modify DIF as much as desired due to flower initiation constraints. For example, from September 21 through October 10, poinsettias being flowered under natural photoperiods should not be exposed to night temperatures exceeding 72°F. Temperatures above 72°F can cause heat delay. We do not recommend night temperature setpoints above 68°F during poinsettia and chrysanthemum flower initiation.

Uneven greenhouse temperatures which result in ''hot spots'' can cause heat delay when the heating setpoints are above 68°F. Because night temperatures are limited to 68°F, the DIF which poinsettias are exposed to during flower initiation is limited to the changing day temperature only. Day temperatures above 68°F will result in a positive DIF, and there is nothing one can do to reduce DIF because of the upper limit on the night temperature. Growth retardants are the method of choice for height control during this time period.

Once poinsettias have developed

Figure 10. Plants respond rapidly to a change in DIF. The center plant was grown at 0 DIF. The plant on the left was exposed one day to a −10°C DIF, while the plant on the right was exposed to a +10°C DIF.

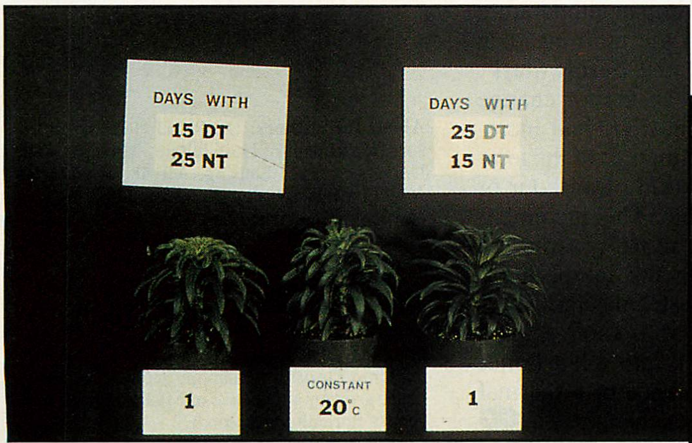


Figure 11. Photoperiod effects response to DIF. All plants were grown under a −7°C DIF. However, length of photoperiod varied. Plants were exposed to 6, 12, 18, and 24 hours of light and 18, 12, 6, and 0 hours of darkness.

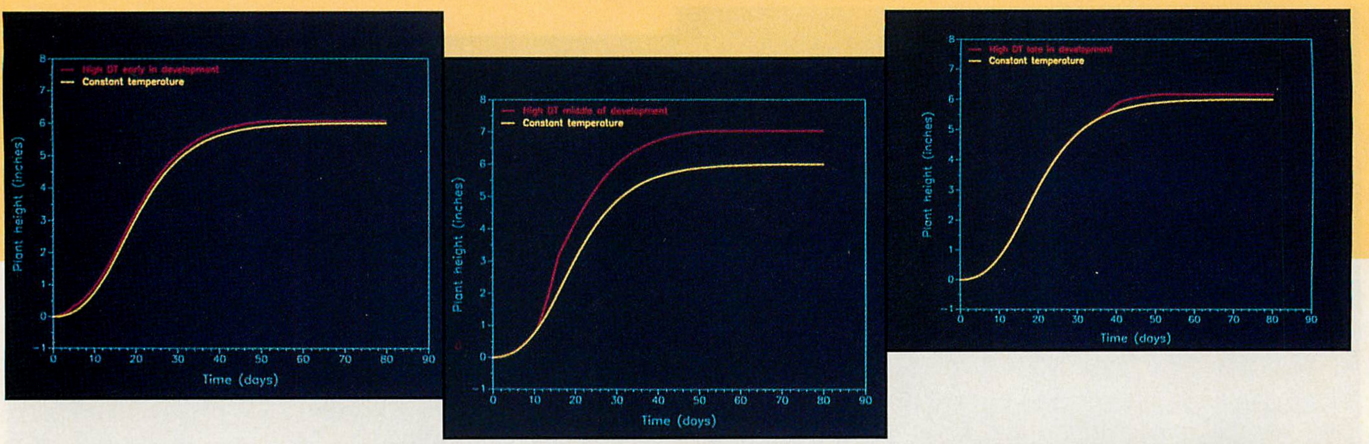


Figure 12. Plant response to DIF is influenced by its current rate of elongation. Figures a, b, and c show the effect of a short term exposure during the a) lag phase, b) rapid growth phase, and c) plateau phase of a poinsettia shoot after pinching. Respose is much greater during the rapid growth phase.

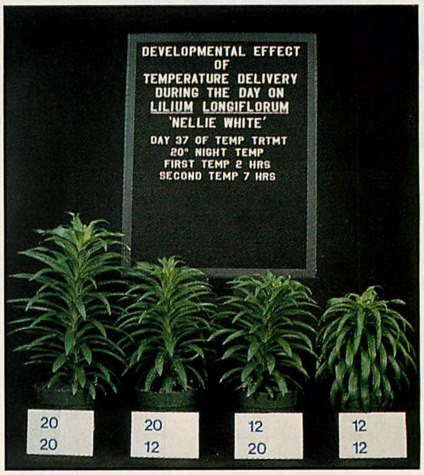


Figure 13. Plants respond strongly to a cool temperature dip at first light. The plant on the far left received a 0 DIF treatment and the plant on the far right received a −8°C DIF. The center right plant shows how a two hour dip in temperature at first light reduces elongation more than a seven hour dip in temperature started two hours after first light (center left).

sufficiently that some bract color is showing and visible flower buds are present, the night temperature can be raised to 77°F for a few nights if needed to help control DIF and internode elongation during bright, warm weather. If plants are exposed to 77°F for only a few nights, heat delay won't occur. However, plant development rate is hastened.

Applying DIF

Decreasing the day temperature at sunrise reduces internode elongation more than reducing the temperature later in the day. Furthermore, a temperature dip for two hours immediately at sunrise is proportionately more effective in reducing internode elongation than reducing the temperature at the end of the day (see Figure 13).

Our research and experience show a rapid drop in temperature at sunrise is critical to obtain maximum height control associated with a negative DIF. Lowering the temperature later in the morning, while helpful in controlling height, is much less effective. However, the longer during the day a low temperature is maintained, the shorter the plant.

To achieve a drop in day temperature at sunrise, heating setpoints (thermostats) must be lowered before sunrise. The timing of the setpoint adjustments is dependent on the heating system. A system with a slow response time (large thermal lag), such as a hot water system, may require its setpoints be lowered 45 to 60 minutes before sunrise. A system with a fast response time (small thermal lag), such as a unit heater, should have its setpoints lowered about 15 minutes before sunrise.

Making Adjustments

Traditionally, growers have been told to open their thermal blankets slowly in the morning so cold air doesn't quickly drop on their plants. Dropping this cold air on the plants at sunrise is actually desirable if a strong DIF response is needed.

We believe the drop in temperature is more critical in the morning than in the afternoon just before dark. While we believe an abrupt change at dark is desirable, a gradual incremental increase (ramping) of the temperature over a period of an hour or so is also acceptable. This incremental increase is a more reasonable method of raising the temperature with hot water and steam heating systems. It reduces the amount of cold water flowing back into a hot boiler and reduces the chance of a thermal shock to the heat exchanger. **GG**

About the authors: Dr. Royal Heins is professor, Department of Horticulture, Michigan State University, East Lansing, MI 48824, and Dr. John Erwin is assistant professor, Department of Horticultural Science and Landscape Architecture, University of Minnesota, St. Paul, MN 55108.

Acknowledgement: The research described in this article was funded in part by the American Floral Endowment, the Bedding Plant Foundation, Inc., the Fred C. Gloeckner Foundation, the Ohio Florist Foundation, and several greenhouse growers supportive of Michigan State University floriculture research.

Growers On

DIF

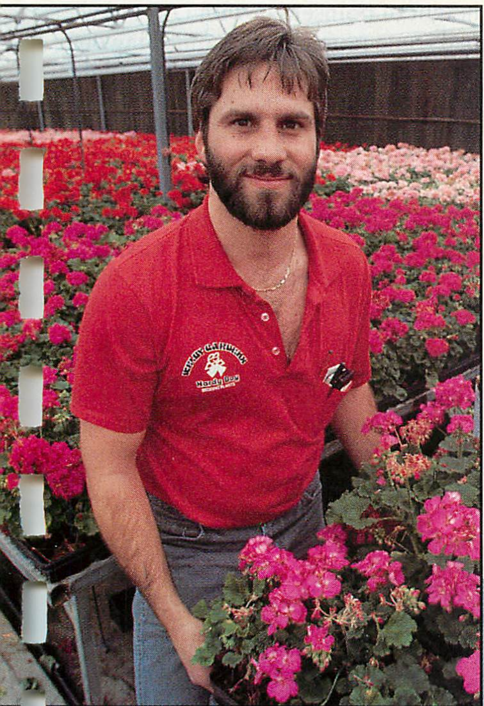
Part II: Hands-on experience from a half dozen leading growers.

by DAVID L. KUACK

DON'T be overwhelmed by the concept of DIF. Although it is a complicated principle many growers are using it effectively for height control. Some growers, during the winter, have completely eliminated or minimized the application of growth retardants.

Growers who have installed environmental computers have found it easier to implement DIF into their production systems. The computers can be programmed to automatically adjust temperatures daily to produce the desired DIF. Those without computers are using DIF by carefully monitoring day and night temperatures and making manual adjustments.

Still uncertain as to whether you should try using DIF? Every interviewed grower who is using DIF recommended that other growers try it. Most have had very good results and plan on continuing to use DIF.



A Cautious Beginning

MARTY GERACE of Welby Gardens, Denver, CO, is a relative newcomer to DIF. Even though he's been using it for only five months, he's pleased with the results on his bedding and potted plants.

"DIF has been effective on most bedding plants, cyclamen, Reiger begonias, and zonal geraniums," says Gerace. "We've just started getting into our major production cycle, so we plan on trying DIF on more crops. Some of our crops grow short naturally, so they don't require using DIF."

In those houses not equipped with an environmental computer, Gerace is trying to maintain a zero DIF on most crops.

"The bedding plants are grown in houses controlled by thermostats, so

"It's easier to maintain a zero or slightly negative DIF, which is very effective in controlling plant height."

— Marty Gerace

it's much more difficult to monitor the temperature. It's been easier to use DIF in those houses in which the temperatures are monitored by an Oglevee environmental computer. However, we are currently doing most of the temperature adjustments in the computer-controlled houses with a time clock rather than with the computer. As we become more comfortable with using DIF we will let the computer do more of the adjustments for us."

One of Gerace's concerns with using DIF is how it will affect the time of flowering.

"We have our crops scheduled so that some come into flower every week," he says. "We haven't been using DIF long enough to determine whether it is going to delay or hasten flowering, but we're watching it carefully." (Editor's note: Dr. Royal Heins says as long as the 24 hour average temperature remains the same, flowering should not be affected.)

Considering the results he has gotten with DIF and the prices he is paying for growth retardants, Gerace doesn't see any reason why he won't keep using DIF when he can.

"The growth retardants we are using are not cheap; the average price is \$30-\$35 per quart. That's nearly \$140 per gallon," he says. "We estimate that we can buy a lot of natural gas for what we pay for growth retardants.

"A grower doesn't need to use a -10°F to -15°F DIF," he continues. "It's easier to maintain a zero or slightly negative DIF, which is *still* very effective in controlling plant height." □

Good Monitors Are Vital

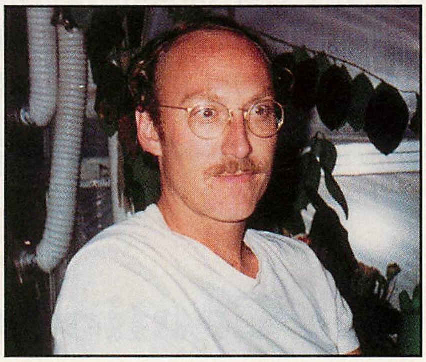
STEVE CLARK of Harry Smith Gardens, Bellingham, WA, finds the most difficult aspect of using DIF is trying to maintain accurate temperature control.

"We try to control the temperature so we can achieve at least a zero DIF," says Clark. "We try to get a two hour temperature dip in the morning and then try to hold the day temperature down as much as possible. That can be tough to do, since we rely on vents and fans for cooling."

Clark, who says he has been experimenting with DIF for three years on bedding plants and regal and zonal geraniums, uses DIF during the winter all the way through to June.

Using Zero DIF to Save Energy

"It's usually during the coldest months that we can maintain a negative DIF," he says. "However, we



have to consider how much energy we are using to heat at night and cool during the day. We try to stay as close to a zero DIF as possible to save on those energy costs."

Since the greenhouses are not equipped with an environmental computer, the thermostats are controlled manually or by Grotron™ climate controllers which have been set on time clocks.

"The Grotrons can give us the DIF automatically in the morning; then, we can manually control the temperature during the day," he explains.

Monitor Temperatures Very Carefully

Clark advises growers interested in applying DIF manually to monitor temperatures very closely.

"Last year we tried controlling the height of poinsettias with DIF but we had some problems in monitoring our temperatures," he says. "The night temperatures dropped too low and the plants received a **positive** rather than a negative DIF. We were fortunate to realize the problem in time, but the plants were delayed a little.

"If you don't have an environmental computer, you have to have good monitoring equipment so that you know precisely what the night and day temperatures are," he continues. "And you have to be willing to walk through your greenhouses at night and in the morning to ensure they are being run at the temperatures you have chosen." □

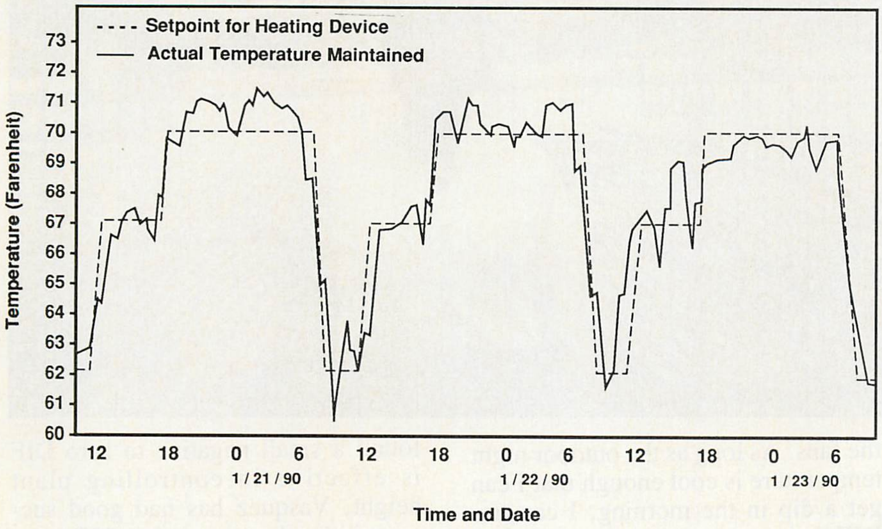
". . . You have to have good monitoring equipment so that you know precisely what the night and day temperatures are."
— Steve Clark

A Computer Makes It Easy

GARY VOLLMER of Four Star Greenhouse, Carleton, MI, began using DIF quite by accident. During the summer of 1988 the company sold too many poinsettia cuttings and ended up running short of cuttings for its own finished crop.

"We were running behind schedule and decided we couldn't apply Cycocel without delaying the early growth that occurs right after pinching," he explains. "With a lot of coaching from Drs. Will Carlson and Royal Heins of Michigan State University, we tried DIF and graphical tracking and were very happy with the results."

Since his initial success with DIF, Vollmer has committed to using it on all of the crops he produces, including plugs and finished plants. One thing that has made it much easier, however, is an Oglevee environmental computer.



By calculating the actual average temperature for a 24-hour period, Gary Vollmer can adjust the day and night temperatures to achieve the average 24-hour temperature that is best suited for optimum growth of the specific crop he is growing.

Easier with an Environmental Computer

"The computer not only enables me to adjust the temperature setpoints based on time, but it changes the setpoints to correspond with sunrise and sunset so that the application of DIF is much more exact," he says.

"Most of the environmental computers on the market have some type of timeline temperature program which growers can use to apply DIF," Vollmer continues. "Otherwise, the time, labor, and costs involved to have someone manually reset the thermostats and monitor the temperature could be prohibitive."

He advises growers to be aware of the temperature changes within a greenhouse — from the floor to the eaves. "Our sensors are set up for the plants on the benches," he says, "but we grow hanging baskets up in

"... (The computer) changes the setpoints to correspond with sunrise and sunset so that the application of DIF is much more exact."

—Gary Vollmer

the eaves where the temperature is normally warmer. At night, the heat has a tendency to rise to the top of the houses. In the morning, as warm air is exhausted out of the ridge vents, the temperature stays warmer longer around the baskets than around the plants on the benches."

The result: The baskets don't receive as high a negative DIF and tend to grow taller.

"Growers who are producing baskets this way may need to use a higher negative DIF, apply more growth retardant, or run circulating or horizontal airflow fans to compensate for these temperature differences," Vollmer explains.

He also admits that it's difficult to use DIF on those crops that he is finishing from June through September.

"Even with our environmental computer, once the outdoor night temperature reaches 60°F or higher, it's not easy to achieve an effective DIF," he says. "With our naturally ventilated houses, if there isn't much convection flow early in the morning, we can't cool down enough to achieve a zero or negative DIF. Even if the greenhouses were equipped with fan and pad cooling, it would be difficult to drop the temperature if the outside humidity were high."

Vollmer learned that with a summer crop of pansy plugs.

"We programmed the computer to provide as much negative DIF as possible. The vents were open all the time and we still didn't get any response," he says. "I held off using a growth retardant hoping that we'd get some cool nights, but unfortunately we didn't. The plugs ended up a little too tall." □

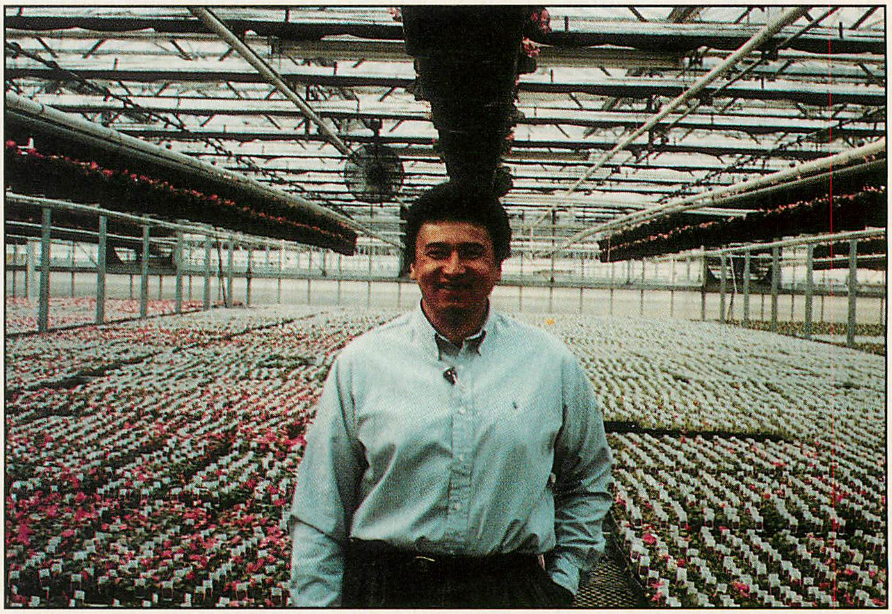
Sold on DIF

VICTOR VASQUEZ of Powell Plant Farm, Troup, TX, is sold on DIF, especially on impatiens.

"I produced my best crop using DIF," says Vasquez. "There was no need to apply a growth retardant since the plants stayed short — and there was no delay in flowering. DIF also works great on salvia, petunias, dianthus, coleus, celosia, verbena, begonias, lilies, and poinsettias."

Vasquez is using DIF on plugs as well as finished packs and pots — some without an environmental computer.

"I'm currently growing tomatoes, peppers, impatiens, and petunias in 500,000 square feet of quonset houses that are not computer-controlled," he says. "There's only one problem: I have to get up at 5:30 a.m. to be in the greenhouses to turn on the fans. As long as the outdoor night temperature is cool enough that I can get a dip in the morning, I can use DIF."



Although most growers have found a small negative to zero DIF is effective in controlling plant height, Vasquez has had good success with a large negative DIF.

"During the first two hours in the

"I produced my best (impatiens) crop using DIF. There was no need to apply a growth retardant since the plants stayed short . . ."
— Victor Vasquez

morning I run a -10°F to -15°F DIF,'' he says. ''During the day I try to maintain a -5°F to -8°F DIF and sometimes I can achieve -10°F. I adjust the day and night temperatures so the average temperature is around 62°F.''

A Matter of Fine-Tuning

Vasquez has been pleased with the results he has gotten with DIF which he says he is now learning to fine-tune with the crops he's growing.

''I applied a negative DIF to a crop of coleus plugs for three to four weeks which resulted in very short plants,'' he says. ''I was able to overcome the DIF effect by increasing the temperature and fertilizer rate.''

Wait and See on Petunias

''I used DIF on petunias; they developed a good root system and are very short and bushy. In fact, there may be too many breaks. Although the increase in breaks shouldn't be a problem, I'm waiting to see if that causes any delay in flowering.''

Vasquez is also learning how much time is needed to re-green plants that are chlorotic from a negative DIF. ''I continually run soil and tissue tests so I know this chlorosis isn't caused by a nutrient deficiency,'' he says.

''DIF is definitely working, but I need to become more familiar with using it to ensure the plants look their best when they are ready to sell,'' he explains. □

Dealing with the Limitations

ED SILVIEUS of Green Circle Growers, Oberlin, OH, sees DIF as another tool to control plant growth — with benefits and limitations.

''The use of DIF is limited by your location,'' he says. ''You may not be able to keep the day temperature as cool as you would like, but if there are cool mornings, you may be able to provide a negative or zero DIF after first light, which is what we do.''

The greenhouse structures often dictate how DIF is used. For instance, some of the greenhouses at Green Circle aren't equipped with cooling pads, making it difficult to run a zero or negative DIF from late April through September. However, the number of greenhouses and the number of plants per crop allow Silvieus to segregate crops by temperature zones.

''In a small-sized operation it may be more difficult to separate crops into zones, particularly if several

"DIF has helped us cut down on the amount of growth retardants we're applying, but we're not disregarding them totally."

— Ed Silvieus

crops are growing on the same or adjacent benches,'' he says.

Type of Heat Makes a Difference

Even with the ability to segregate crops, Silvieus points out that trying to use DIF can become complicated by the type of heating system you have installed.

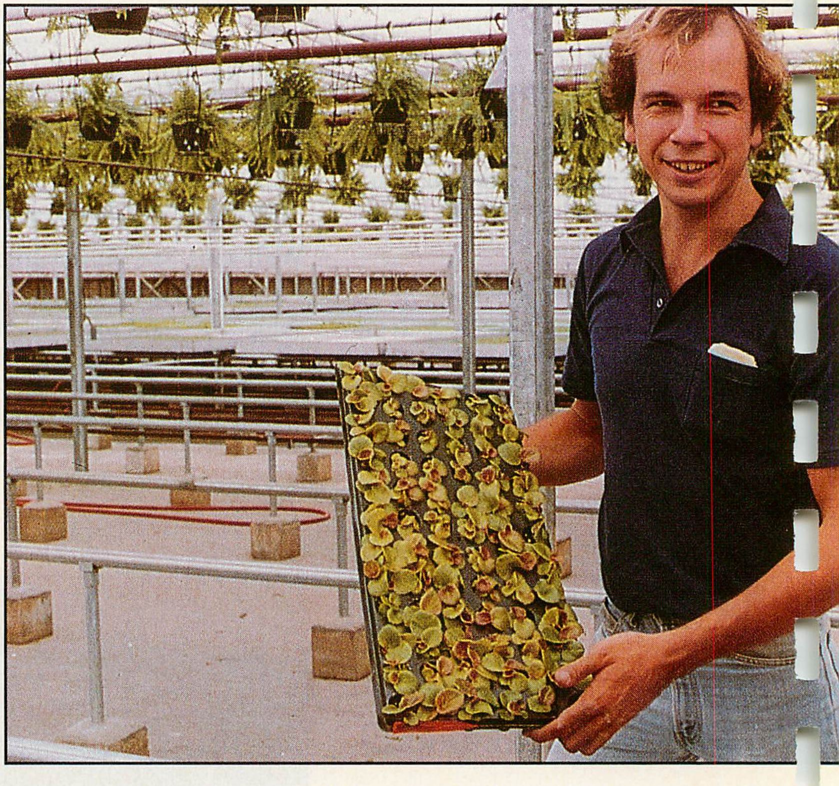
''Last year, our Easter lilies were grown on porous concrete, which is equipped with hot water floor heat,'' he says. ''We encountered difficulty trying to get a sudden drop in temperature to achieve a negative DIF. You see, a heated floor doesn't react to a change as quickly as overhead heat. Although we were dropping the air temperature from 68°F to 60°F early in the morning, we weren't able to achieve the same drop in the medium temperature. The warmer medium temperature kept the plants actively growing.''

Still Relying on Growth Retardants

The result? ''We had to apply as much growth retardant as if we weren't using DIF,'' he says. ''This year, we're growing some Easter lilies with only overhead heat to determine if we can achieve some height control with a negative DIF.''

If anything, this experience taught Silvieus the importance of growth retardants. ''DIF has helped us cut down on the amount of growth retardants we're applying, but we're not disregarding them totally,'' he says.

''We're also looking at the effectiveness of growth retardants on negative DIF-treated plants. Although not yet confirmed, it appears that growth retardants aren't as effective when we use a negative DIF as when we run traditional temperature regimes.'' □



It All Depends on the Weather

RON DERRIG of Natural Beauty has three criteria for success with DIF: location, location, and location. With Natural Beauty's three facilities, he's also the grower with the widest geographical experience with DIF.

Here's a rundown of how it works at each range:

Weather Conditions Dictate Use

''At our Apopka, FL operation, we can only control the night temperature three to four months out of the year,'' explains Derrig. ''We are currently computerizing the monitoring of the environment, but the system will not control the environment.

''During a normal winter we can use DIF from mid-December through mid-March. If we experience a cool fall or spring we could use it for a longer period of time — and if we have a warm winter

"As soon as the humidity turns muggy . . . it's not possible to use DIF in Wisconsin, because the fan and pad cooling just won't work."
— Ron Derrig

Year-Round Use in Georgia

Although Derrig is just beginning to implement DIF at the Georgia operation, he expects to be able to use it year-round for height control.

"The greenhouses are up on a mountain and the outdoor night temperatures usually don't get above 60°F, even in the hottest part of the summer," he says. "However, we have to watch for wide extremes between the day and night temperatures or otherwise we can encounter problems with crops such as pansies, whose leaves become disoriented and start to stand straight up.

"We find that the zonal geraniums produced in Georgia respond very well to a negative DIF," he adds. "We eliminated a lot of internode stretch and promoted basal branching with DIF. More importantly, we were able to continue to irrigate and fertilize the plants, instead of starving them of water and nutrients and relying solely on Cycocel."

It has been a real learning process, however. "We found one situation where using a zero DIF is better than a negative DIF," he explains. "We were trialing plants in an experimental bark mix which was tying up some of the nitrogen from the fertilizer we were applying. We increased the fertilizer rate but we also had to contend with the chlorosis caused by a negative DIF. By going to a zero DIF we were still able to control the plant height **and** eliminate the chlorosis."

Dealing with Wisconsin Humidity

Derrig has not worked much with the Wisconsin facility, but plans on doing more with that operation.

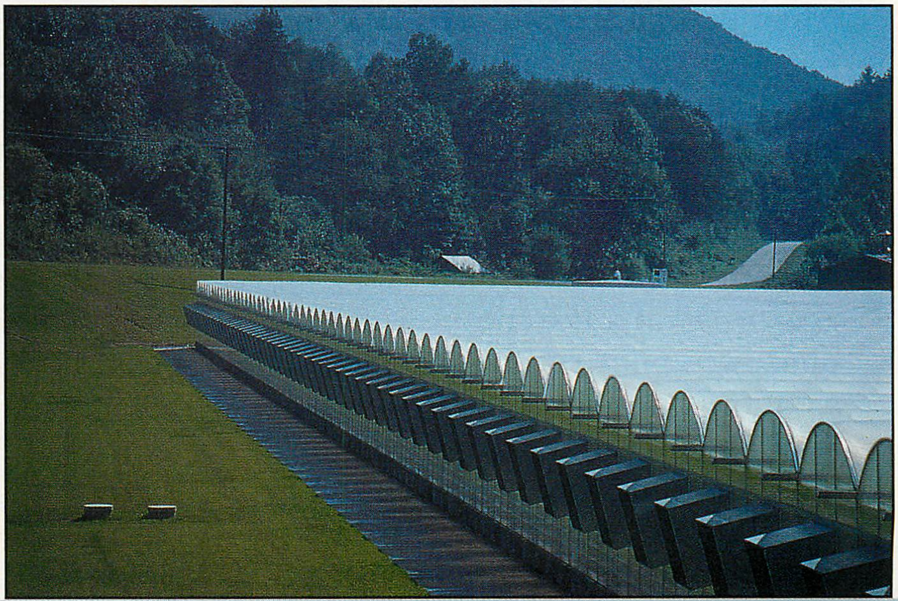
"If the humidity turns muggy in August and September, as it did in 1988, it's difficult to use DIF in Wisconsin," he says. "But in a normal weather year, DIF can be used as long as there is a cooling system to lower the greenhouse temperature." □

we use it for only about a month."

To create a negative DIF, Derrig runs the night temperature at 62°-64°F for a crop like impatiens. Then, about an hour before sunrise, he drops the temperature about 4°F. This shock treatment is enough to control plant growth.

"We turn the thermostats down and let the fans flush the air out of the greenhouses," he says. "We don't have to worry about heating the greenhouses during the day since the sun does that naturally. But here in Florida, the difficult part is controlling the temperatures — both day and night. During February and March, for instance, the day temperature in the greenhouse is 78°-80°F. We can't get it any cooler than that even using fog and fans."

Growing plants atop a Georgian mountain, where temperatures can be extreme, creates a special challenge for Derrig's use of DIF.



Interested in Applying DIF?

MOST growers who have tried DIF believe it is a valuable production tool that you can use to control plant height. If you're considering trying DIF, here are a few suggestions:

1. Try DIF on a limited basis within one zone or greenhouse with a small number of plants rather than an entire range.

2. Start with a zero DIF. If it doesn't provide adequate height control, implement a negative DIF in one-degree increments. Plant response is greater when you go from a positive DIF to a zero DIF than when you go from a zero DIF to a negative DIF. A commitment to trying to keep the day temperature cooler will go a long way towards controlling plant height.

3. Because warm air rises, plants grown toward the top of a greenhouse may not receive the same DIF as plants grown on the benches below. Fans, such as circulating or horizontal air flow, can be used to maintain an even temperature throughout the greenhouse.

4. When trying to drop the temperature in the morning, be aware that different heating systems retain heat for varying lengths of time. Hot water and steam pipe systems will hold the heat longer than unit heaters. Overhead systems dissipate heat faster than in-floor systems.

5. You don't need an environmental computer to use DIF, but you must make the commitment to monitor the greenhouse temperatures closely day and night. This is why it is best to start out using DIF in just a small area.

6. If you run into problems with DIF, remember you can always go back to your old production methods, including using growth retardants. □

Choosing the Best Temperature for Growth and Flowering

by ROYAL D. HEINS

PLANT responses, including internode elongation, leaf unfolding, and flower initiation, are all affected by temperature. We have already discussed the effect of temperature on internode elongation in the two previous articles on DIF. This article will examine the effect temperature has on rate of growth and flower initiation.

How Temperatures Affect Plant Response

ALL plant responses to temperature follow a similar pattern. Below some temperature called the base temperature, there is no response. As the temperature increases, the response increases to a maximum level at the optimum temperature.

Once the temperature goes above that optimum temperature, however, the response decreases, often rapidly, back to zero. This temperature/plant response relationship is called the temperature response curve (Figure 1).

Growth at any moment in time is

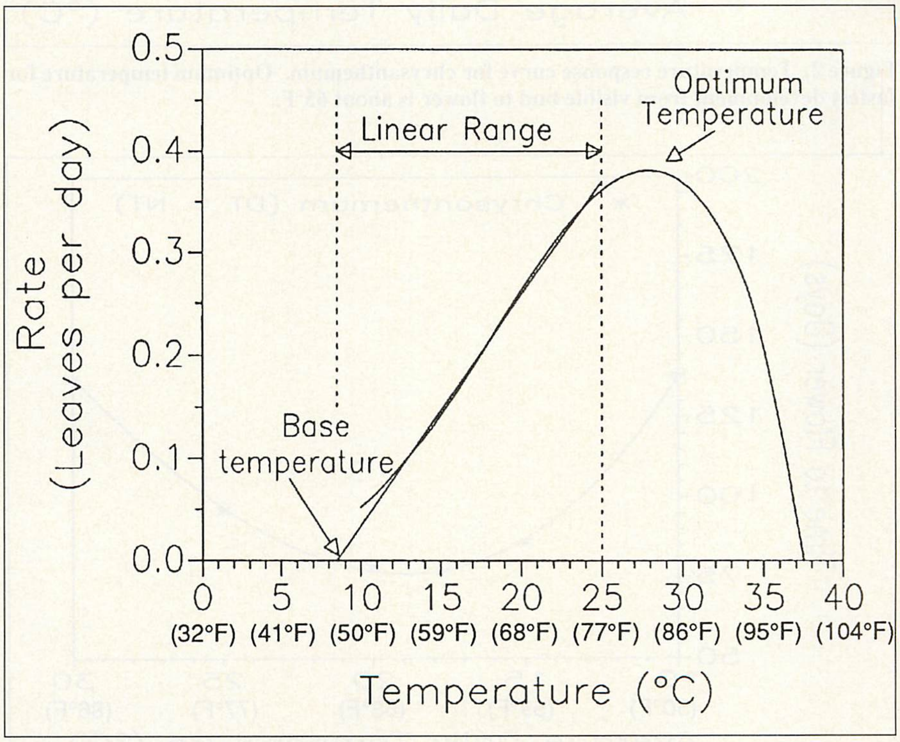


Figure 1. Typical temperature response curve.

Plant development: The series of processes (including leaf unfolding, internode elongation, and flower initiation) from the start of growth until the death of a plant.

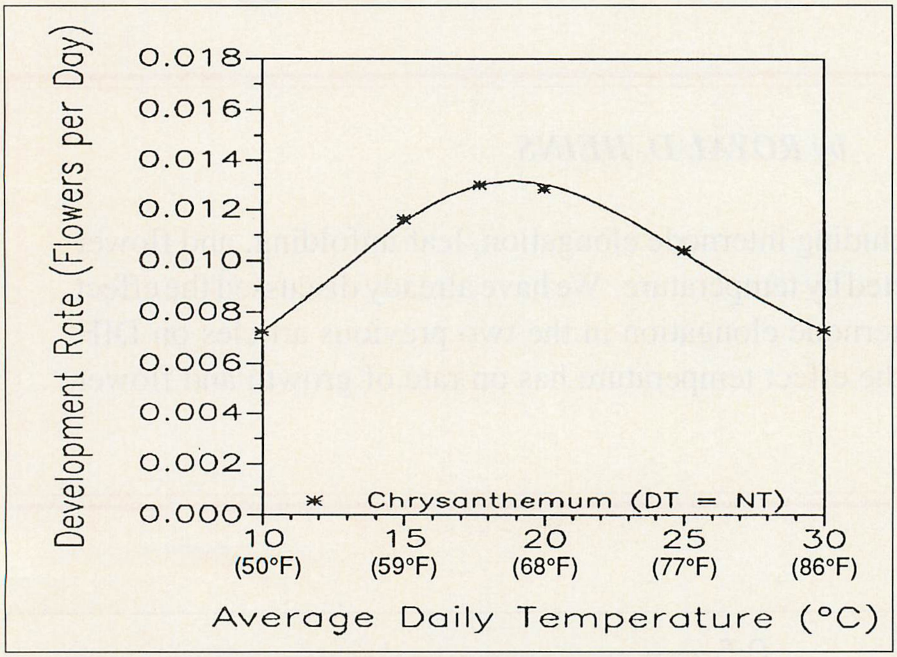


Figure 2. Temperature response curve for chrysanthemum. Optimum temperature for fastest development from visible bud to flower is about 65°F.

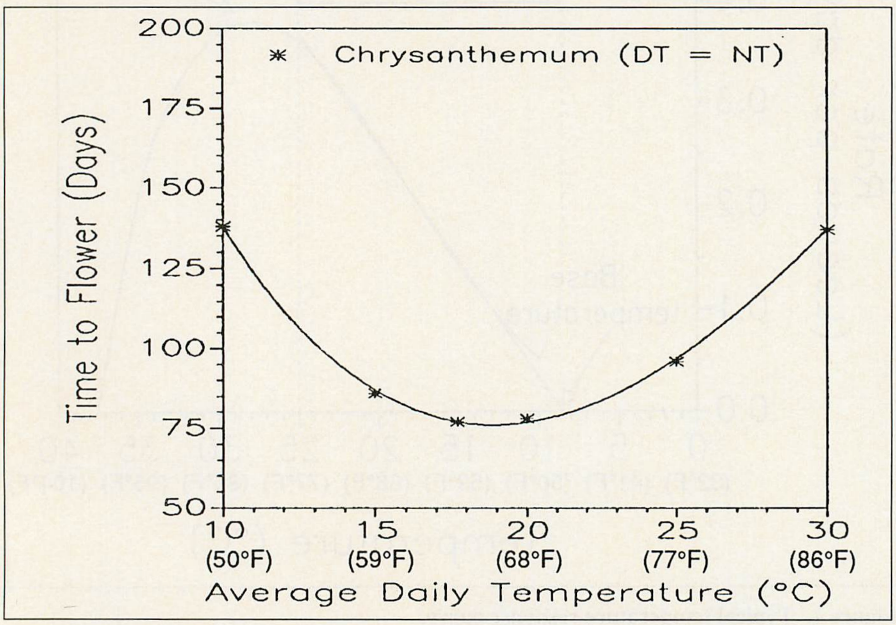


Figure 3. Time to flower for chrysanthemums grown at different temperatures. Growing mums above 65°F after visible bud delays flowering.

controlled by instantaneous plant temperature. The cumulative growth during a 24-hour period is the sum of the individual growth rates at each temperature during that period.

If you wish to grow plants as quickly as possible, it is important to know the optimum temperature which produces the fastest rate of development. Development is slower both below and above the optimum temperature. The optimum temperature varies among species and is surprisingly low for some commercially produced plants.

For example, the optimum temperature for the fastest development of chrysanthemums from visible bud to flower is about 65°F (see Figure 2). This means growing mums above 65°F after the visible bud stage doesn't hasten development, but delays flowering (see Figure 3).

The Linear Temperature Range

Figure 1 shows a temperature range called the "linear range." In the linear range, growth rate increases linearly with an increase in temperature. For many plant responses, the linear range starts near the temperature where growth first begins (base temperature) and continues to within about 5°-7°F of the optimum temperature.

As long as the day and night temperatures stay within the linear range, daily plant growth is directly related to the 24-hour average temperature.

Response to Average Temperature

In the linear range, plants exposed to a positive, negative, or zero DIF grow at the same rate as long as the 24-hour average temperature is the same.

For example, if plants were grown at a 12-hour day of 70°F and 12-hour night of 60°F (positive DIF); or a 12-hour day of 60°F and 12-hour night of 70°F (negative DIF); or at constant

Growth rate: The speed at which a plant progresses through or from one developmental stage to the next. Growth rate includes all plant processes, including internode elongation, leaf unfolding, and flower induction, initiation, and development.

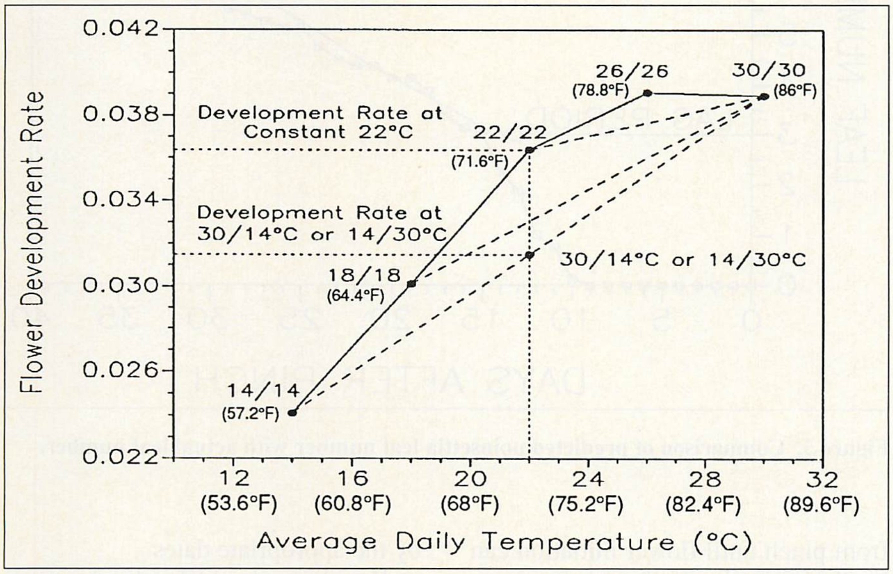


Figure 4. Temperature response curve for flower development rate in Easter lily. Compare the development rate at a constant 71.6°F (22°C) with the development rates at 86°/57.2°F (30°/14°C) and 57.2°/86°F (14/30°C). Each combination has the same 24-hour average temperature 71.6°F (22°C), but the development rate at a constant 71.6°F (22°C) is greater than the rate at either combination. The 57.2°/86°F combinations assume 12 hours at each temperature per day.

65°F for 24 hours (zero DIF), all of the plants would develop at the same rate and would flower at the same time because the 24-hour average temperature is the same (65°F).

However, the height of these plants would be very different due to their response to DIF. The plants grown at a negative DIF would be the shortest, while the plants grown at a positive DIF would be the tallest.

Temperatures are not always maintained within the linear range. When either the day or night temperature goes outside the linear range, the daily growth rate is not directly related to the average daily temperature. Instead, the daily growth rate is the sum of the individual growth rates that occur for a 24-hour period.

The Fastest Growth Rate

Plants never grow faster than when they are exposed to the same day and night temperature. A combination of day and night temperatures *within* the linear range results in a growth rate equal to the rate from the same day and night temperature of the same average temperature. A combination of day and night temperatures *outside* the linear range result in a growth rate less than the rate from the same day and night temperature (see Figure 4).

Consequently, if a crop is behind schedule, there is no way you can speed up the growth rate beyond that of a constant temperature by using a combination of warm days and cool nights or cool days and warm nights. The fastest way to accelerate a slow crop is to maintain a constant 24-hour temperature at or near the optimum temperature.

Effect of DIF on Growth Rate

The growth rates of plants grown at the same 24-hour average temperature can be different when plants are grown with different DIFs, depending on whether the day and night temperatures are in or out of the linear range. What is important is the actual temperature and the total time at which each temperature occurs.

How does changing DIF affect crop timing? Changes in DIF may or may not affect crop timing depending on if the temperatures before and after the change in DIF were inside or outside the linear range, and if there has been any change in the 24-hour average temperature. If the 24-hour average temperature remains the same and temperatures are in the linear range, then the growth rate doesn't change. However, if the change in DIF results in a change in the 24-hour average temperature or if the day or night temperature moves into or out of the linear range, then the growth rate is affected. Consequently, changing DIF can have a variable effect on crop timing.

Typically, night and day temperatures fall in or near the linear range, especially in winter. Growers often adjust DIF from a positive number to nearly zero by venting earlier in the day.

If the night temperature is not raised to compensate for the cooler day temperature, the average 24-hour temperature decreases, causing the growth rate to decrease. ❑

Speeding Up Plant Growth

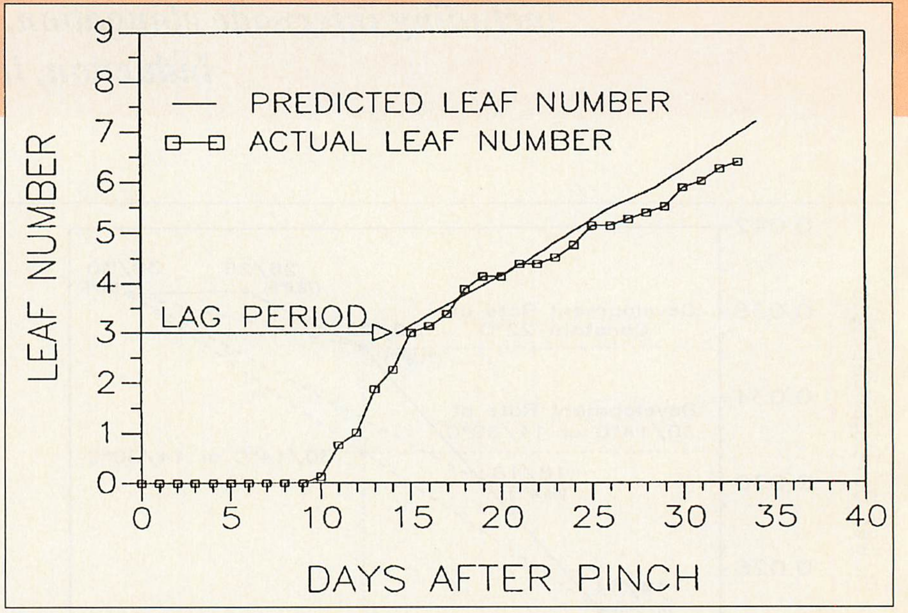


Figure 5. Comparison of predicted poinsettia leaf number with actual leaf number.

KNOWING and understanding the shape of a temperature response curve for a particular species can be useful when producing a crop. Unfortunately, temperature response curves for most floriculture crops have not yet been determined. These curves would be most useful when crops are slow. In this situation, plants could be grown at the optimum temperature for the fastest growth rate.

As an example, consider a poinsettia crop which is growing slowly and is pinched later than normal. If the plants are grown at the recommended temperatures after a normal pinch, lateral shoot growth will be less than required for the desired finished product by the normal date of flower initiation (September 21-25 in most of the U.S.). (For poinsettias, the recommended night temperature is 65°F and the day temperatures depend upon the weather.) Unless flowering is delayed so that adequate lateral shoot growth can occur, the finished poinsettias will be smaller than desired.

If the desired leaf number on the lateral shoots is known at flower initiation, the required leaf unfolding rate from pinch until flower initiation can be determined. If the temperature-driven leaf unfolding response curve (which looks similar to the curve in Figure 1) is known, growers can determine if plants are capable of unfolding leaves at this rate and what average daily temperature is necessary to achieve this leaf unfolding rate.

If the leaf unfolding rate is biologically not possible (for example, poinsettias cannot unfold leaves faster than about 1/4 of a leaf per day), plants can be grown at the maximum leaf unfolding rate temperature in order to minimize delaying the start of flower initiation.

Programming Plant Size

The real future of temperature response curves lies in their use with environmental computers. I see the day when temperature response curves will be programmed into computers.

Growers will enter the dates for planting, pinching, start of short days, and flowering and desired final plant height into computers which will automatically calculate the required temperatures to achieve the desired plants by the appropriate dates.

Based on required development over time and the plants' actual development, computers will automatically recalculate temperature setpoints to properly time crops if desired temperatures are not achieved or if crop development deviates for whatever reason.

Predicting Development

The ability to predict development over time with a temperature response curve is shown in Figure 5. Poinsettias were pinched and the actual leaf number was recorded daily. Average hourly temperatures were collected and used to calculate the expected (predicted) leaf number over time.

The predicted leaf number, calculated solely from temperature, is closely correlated with actual leaf number (see Figure 5). With poinsettias, the first three leaves unfold in a different pattern than subsequent leaves, and a lag period is therefore seen on the graph.

It is a minor step from *predicting* leaf number with the temperature response curve to *controlling* greenhouses with the curve. ❑

How Temperature Affects Flower Initiation

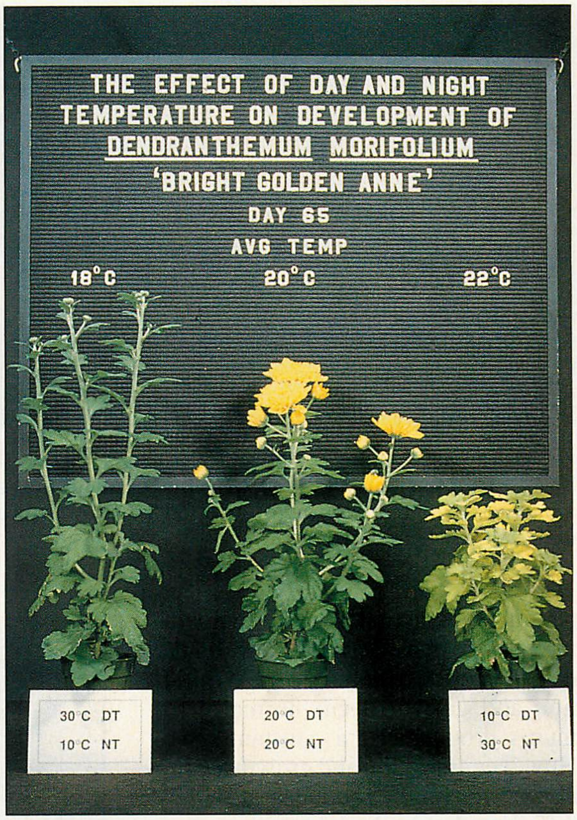


Figure 6. Effect of absolute temperature on chrysanthemums grown at approximately the same average daily temperature.

GROWERS have the knowledge to manipulate temperatures to provide each of their crops with an optimum temperature which will ensure the desired growth rate and plant height (DIF). However, weather conditions and greenhouse facilities may prevent growers from maintaining optimum temperatures. Not to be overlooked is the influence temperature has over flower initiation and development.

Photoperiod and temperature are the two environmental factors that control flower initiation. While photoperiod directly controls flower initiation in some plants, including poinsettias, mums, and kalanchoes, temperature has either a direct or indirect effect on initiation in all plants.

Figure 7. Influence of day and night temperature on flowering of poinsettia. Horizontal rows represent common day temperatures; vertical rows represent common night temperatures.

Temperature directly affects flower initiation in Easter lilies through vernalization. It indirectly affects initiation in day-neutral plants, such as African violets and gloxinias, by influencing rate of development. Temperature also indirectly affects initiation in photoperiodic plants because initiation only occurs in these plants when the temperature falls within a certain, often narrow, range.

With photoperiodic plants, it's important to understand that the day and/or night temperatures are more important to flower initiation than the 24-hour average temperature.

Figure 6 shows mums grown at nearly the same average daily tem-

Flower initiation: Visible organization of flower parts at the stem tip.

Figure 8. Effect of day temperature from 29° to 14°C (84.2° to 57.2°F) (left to right) on flower initiation of poinsettias grown at a common night temperature of 20°C (68°F). Flowering occurred under all day temperatures.

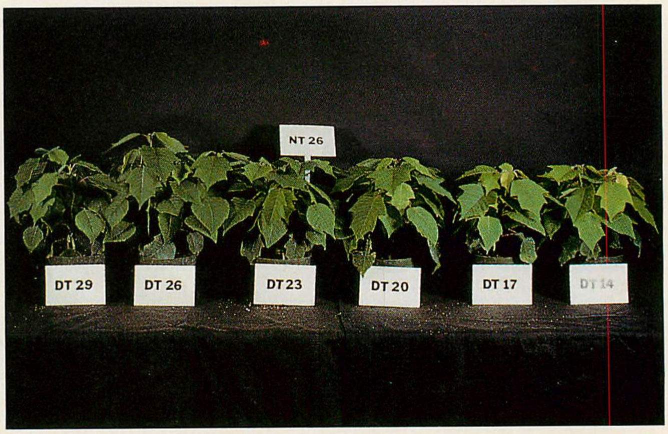


Figure 9. Effect of day temperature from 29° to 14°C (left to right) on flower initiation of poinsettias grown at a common night temperature of 26°C (78.8°F). Flowering was inhibited under all day temperatures.

perature (the actual average temperature varies because the length of the day and night are not the same). Initiation and growth occur normally for mums produced at a constant 68°F. However, initiation and growth are not normal for mums produced at widely different day and night temperature combinations, such as 50°F/86°F, even though the average temperature is about the same (68°F).

Influence of Day and Night Temperatures on Flowering

For proper flowering, it's critical to know whether the day or night temperature—or both—is most important to flower initiation. In some species, initiation is equally affected by the day and night temperature. In other species, initiation is primarily affected by either the day or the night temperature.

The control of night temperature is particularly critical for flower initiation in poinsettias (see Figure 7). As long as the night temperature remains below 73°F, and the plants are under short days, flower initiation will occur

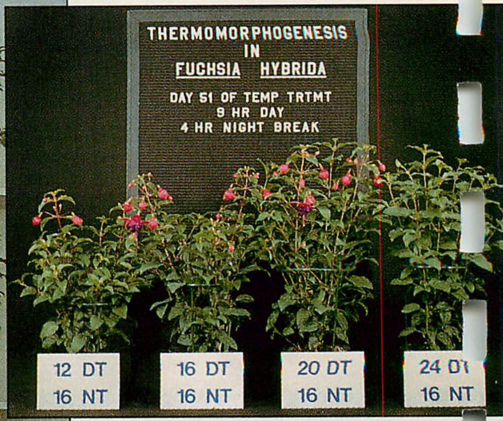


Figure 10 (left). Effects of day and night temperatures from 12° to 24°C (53.6° to 75.2°F) on flowering of fuchsias. Horizontal rows represent common day temperatures; vertical rows represent common night temperatures.

Figure 11 (above). Effect of increasing day temperature from 12° to 24°C on fuchsias grown at a common night temperature of 16°C (60.8°F).

Vernalization: Cold-moist treatment applied to a bulb or plant to induce or hasten flower development.

over a very wide range of day temperatures (see Figures 7 and 8). However, if the night temperature exceeds 73°F, flower initiation won't occur, regardless of the day temperature (see Figures 7 and 9).

With fuchsias, which require long days to initiate flowers, day temperature is more important than night temperature in controlling initiation (see Figures 10 and 11). Fuchsias grown at high day temperatures, above 72°F, were later to flower.

Heat Delay

A more typical situation is where both the day and night temperature influence flower initiation and development (see Figures 12 and 13).

Most mum growers know about heat delay in the summer. They sometimes open blackcloth after dark, allowing some heat to escape from the greenhouses.

However, our studies show high day temperatures are as important in causing heat delay in mums as high night temperatures (see Figure 12). We found flowering was delayed as much on mums grown at 75°F during the day as mums grown at 75°F at night.

Heat Delay in the Winter?

Less well known to mum growers is heat delay during the winter. Time to flower in mums is influenced not only by temperature, but by the total amount of light the plants receive. Valentine's Day and Easter crops sometimes develop slowly due to low light conditions.

The natural reaction when a mum crop is slow is to raise the temperature to speed up development. However, increasing the temperature on a slow mum crop will only be useful if the greenhouse temperature is less than 65°F. Once the day or night temperature reaches 65°F, increasing either temperature will slow flower development.

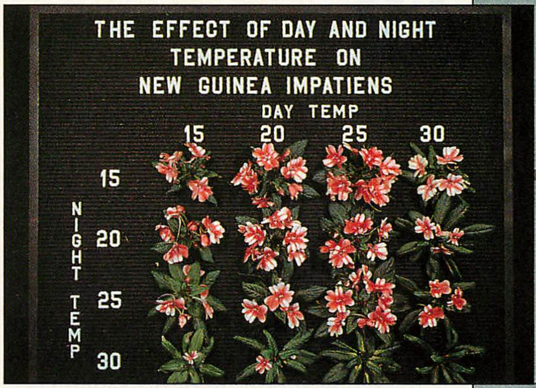


Figure 12 (right). Effects of day and night temperatures from 12° to 24°C (53.6° to 75.2°F) on flowering of chrysanthemums. Horizontal rows represent common day temperatures; vertical rows represent common night temperatures.

Figure 13 (above). Influence of day and night temperatures from 15° to 30°C (59° to 86°F) on flowering of New Guinea impatiens. Horizontal rows represent common night temperatures; vertical rows represent common day temperatures.

A heat delay problem with mums can also occur when mums and Easter lilies are grown in the same greenhouse section. The optimum temperature for maximum development rate of Easter lilies is closer to 75°F. A grower with a slow lily crop can raise the temperature to 75°F to hasten development, although a price is paid for temperatures above 70°F. Lily flower abortion increases as the temperature exceeds 70°F. Development of mums will be slowed if they are grown with lilies at 75°F because the temperature has increased above the optimum temperature for mums.

To Avoid Delays in Flowering

Generally, the most critical time for precise temperature control is during flower induction, initiation, and early flower development. For example, heat delay in poinsettias occurs most often from September 21 through October 20.

Once flower buds are visible on poinsettia shoots or any pigmentation is visible on the immature leaves, plants are much less sensitive to heat delay. Sensitivity to heat delay decreases in most species as flowers develop. ❑

Putting It All Together

IN order to combine the effects of temperature on plant height (DIF), rate of growth (time to maturation), and flower initiation, you need to know a plant's stage of development and how different temperature combinations (day, night, and average) influence a plant at that particular stage. You must set priorities when selecting the best temperature.

If plants are initiating flowers, you must choose a temperature range based on the optimum temperature for initiation. The ability to modify DIF and the average daily temperature is limited by flower initiation considerations.

For example, during poinsettia flower initiation the night temperature setpoints should not exceed 68°-70°F, even if a negative DIF is desired and the day temperature is above 70°F.

If plants are not initiating flowers, then the 24-hour average temperature is most important. DIF can be adjusted over a wide temperature range as needed to decrease or increase plant height as long as temperatures are in the linear range and the 24-hour average temperature remains the same.

If plants are behind or ahead of schedule, the average 24-hour temperature must be adjusted to increase or decrease the rate of development. In such cases, changes in DIF are limited by the average temperature.

For example, consider a lily crop is behind schedule and you want to control height with DIF. To have a high enough 24-hour average temperature for the desired rate of development--while achieving a significant negative DIF--might require night temperatures above 70°F. But remember--as the night temperature increases above 70°F, flower bud abortion on lilies increases. A negative DIF may have to be sacrificed to ensure the average temperature is warm enough to achieve the required development rate. Using a negative DIF on this crop may be limited to a dip in temperature during the first two hours of light. (Growers have found a two-hour temperature dip at sunrise is most efffective in achieving maximum height control.)

Choosing Day and Night Temperatures

Choosing day and night temperatures is critical to the success of producing any greenhouse crop. Previously, DIF was not a concern to growers even though their crops were exposed to some DIF every day.

DIF Complicates the Selection

Applying DIF to control height complicates the process of temperature selection because changes in DIF can alter the average daily temperatures and/or interfere with flower initiation. Knowing the temperature requirements for flowering and development of each crop is critical to properly apply DIF.

A Reminder

DIF is defined as the mathematical DIF-ference between the day and night temperature.

A **positive DIF** occurs when the day temperature is warmer than the night temperature.

A **negative DIF** occurs when the day temperature is cooler than the night temperature.

Zero DIF is when the day temperature and the night temperature are equal. DIF is applicable to any day and night combination.

Plant height decreases as night temperature increases.

Plant height increases as the day temperature increases.

If you are unsure about the temperature requirements for a specific crop, continue growing plants as in the past or ask other growers or extension specialists who know. Otherwise, improper selection and application of temperatures may result in poorly timed or nonflowering plants. ❏

About the author: Dr. Royal D. Heins is professor, Department of Horticulture, Michigan State University, East Lansing, MI 48824.

The research which generated the information for this article was funded in part by the American Floral Endowment, Bedding Plants Foundation, Inc., Paul Ecke Poinsettias, Fred C. Gloeckner Foundation, and several greenhouse growers supportive of Michigan State University floriculture research. Dr. Meriam Karlsson of the University of Alaska, Dr, Robert Berghage of New Mexico State University, and Dr. John Erwin of the University of Minnesota contributed to this article through experimentation and discussion while students at Michigan State.

Understanding and Applying Graphical Tracking

by ROYAL D. HEINS and WILLIAM H. CARLSON

PREVIOUS articles in this series have examined how DIF influences rate of internode elongation and how temperature influences rate of plant development and flower initiation. But there are still some questions regarding plant development that need to be answered. This article will address some of those questions.

A Road Map for Growth

HOW do growers know if a crop is too tall or short at a particular stage of development? How do they know if a crop is ahead or behind schedule? How do they know what effect a change in DIF or the average daily temperature has had on a crop—or whether a change in DIF or average daily temperature has been the correct change?

One method that can help answer these questions is graphical tracking. Graphical tracking is a grower management technique in which actual plant height or development is compared with desired plant height or development. Crop management decisions are then made based on the information obtained from this comparison.

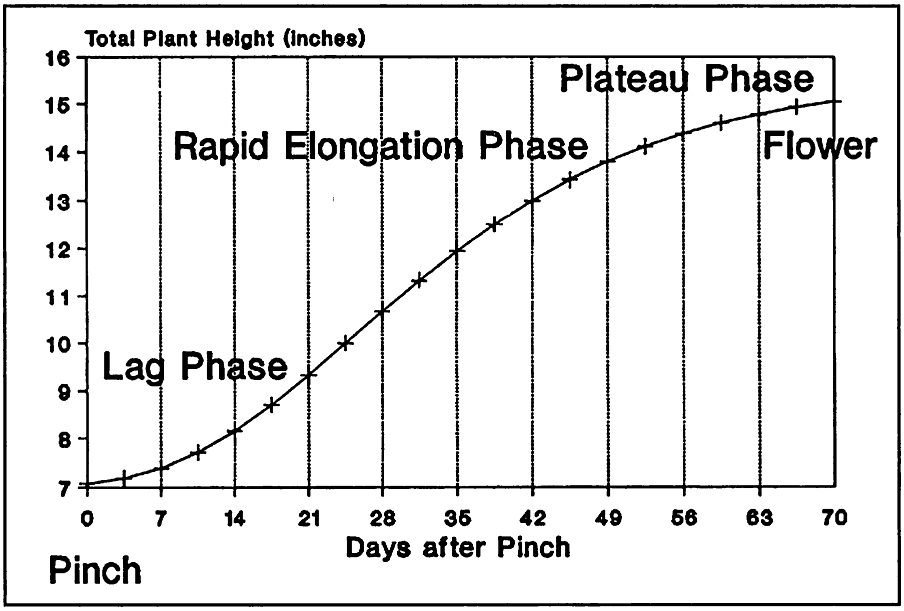


Figure 1. Sample stem elongation curve for poinsettias and chrysanthemums.

At Michigan State University we have developed the information which allows us to graphically track poinsettias, chrysanthemums, and Easter lilies.

An analogy to graphically tracking height is the use of a road map. Comparing your actual location with a map allows you to determine if you are on the correct road or if you are going in the wrong direction. Similarly, comparing actual height during development with desired height tells you if your plants are short, tall, or the correct height.

Comparing Actual and Predicted Height

When producing a crop, the plants have an initial height when the crop is started. The crop is to be marketed at some future date at a specific height or range of heights. If initial height and the required final height are known, along with the length of the production cycle, and how the plant increases in height (stem elongation curve), then the actual height can be compared with the predicted height and adjustments can be made.

Graphically Tracking Poinsettias and Chrysanthemums

Graphically tracking poinsettias and chrysanthemums is very similar. Five pieces of information are necessary to graphically track these two crops properly. They include:

1. The pinching date.
2. The flowering date.
3. The initial height, which includes the height of the pot plus the height of the mother (main) shoot.
4. The desired minimum and maximum height at flower.
5. The stem elongation curve.

The first four items are easily obtained and are known by most growers. The stem elongation curve for poinsettias and mums is, however, more complex and not easily developed without a knowledge of how a lateral shoot develops on determinate-growing plants, such as poinsettias and mums. In these plants, flowering shoots terminate with a flower.

Lateral shoot development on poinsettias and mums follows a similar pattern after pinching. Growth is initially slow (lag phase) as apical dominance is overcome. The growth rate then increases to a maximum during the rapid elongation phase. The growth rate then gradually decreases as flowers develop (plateau phase), and eventually stops as the flowers mature.

The stem elongation curve for poinsettias and mums has five parts (see Figure 1). The curve (1) starts at pinch, (2) has an initial lag phase, (3) followed by a rapid elongation phase, (4) a terminal plateau phase, and (5) ends at flowering.

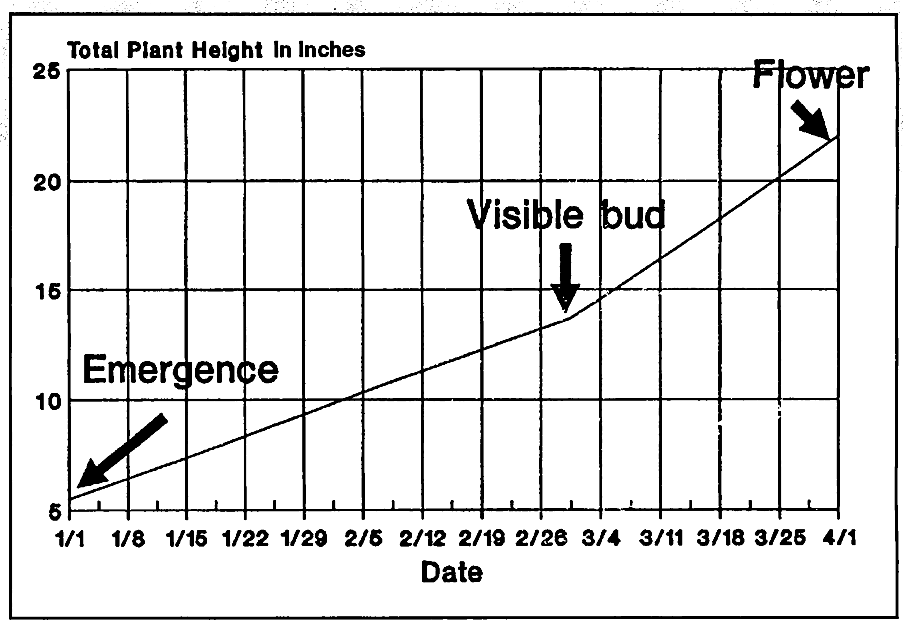


Figure 2. Sample stem graphical tracking curve for Easter lilies.

Graphically Tracking Easter Lilies

Five pieces of information are necessary to graphically track Easter lilies. They include:

1. The plant emergence date.
2. The visible bud date.
3. The flower date.
4. The desired minimum and maximum height at flower.
5. The stem elongation curve.

The first four items are easy to obtain and are generally known by most lily growers. In contrast to the stem elongation curves for poinsettias and mums, the curve for Easter lilies is simple.

The easiest way to develop the stem elongation curve for Easter lilies is to assume the plants double in height from visible bud to flower. This means the plant height at visible bud, not including the pot, is half of the height at flowering (see Figure 2).

Although this assumption is generally reliable, it is important to understand that the increase in plant height from visible bud to flower is not dependent on the height at visible bud.

Based on our experiences, the increase in lily height from visible bud to flower can be as little as 5 inches on healthy lilies grown under a large negative DIF (-15;dgC) or when A-Rest is applied. The only time the increase in height is less than 5 inches is under conditions of massive root loss. In our discussion of graphical tracking we are assuming the plants are healthy and have not experienced such root loss.

Determining the Increase in Lily Height

The maximum increase in height from visible bud to flower on healthy lilies is at least 12 to 15 inches under low light—crowded, positive DIF conditions. Therefore, the height increase from visible bud to flower on healthy lilies can range from 5 to 15 inches, irrespective of the height at visible bud.

While this 5- to 15-inch height range exists, it's still reasonable to assume lilies will double in height from visible bud to flower when designing a graphical tracking plot. However, if a negative DIF or growth regulator is applied, lilies can be prevented from doubling in height. Likewise, if lilies are short at visible bud, the height can more than double if they are grown at a positive DIF.

Considering a 22-inch lily at flower, the flowering plant height is 16 inches (22 inches minus 6 inches for the pot size). Half of 16 inches is 8 inches. Assuming an 8-inch increase in height from visible bud to flower, then the plant height can only be 8 inches at visible bud. (Eight inches plus 6 inches for the pot equals 14 inches total.) Eight inches is half of the final height in this situation. Therefore, doubling in height from visible bud to flower is a reasonable assumption.

A 6-inch lily (12 inches total including a 6-inch pot) at visible bud can grow to 18 inches (24 inches total including a 6-inch pot) given environmental conditions which promote stem elongation.

Doing Graphical Tracking

The practice of graphical tracking consists of four steps:

1. Creating the graph.
2. Measuring plant height and plotting the height on the graph.
3. Comparing actual height with predicted height and responding to the situation with no changes, or changes in DIF and/or growth regulator applications.
4. Repeating steps 2 and 3 every three to four days.

Creating a Graph for Poinsettias and Mums

Creating a graph for poinsettias and mums is easy with a computer program, but is an involved process when attempting to do it by hand.

The values in Table 1 show the percentage of final height a lateral shoot should equal during development from pinch to flower. Multiplying the percentage (as a decimal) for each time (shown in Table 1) by the total lateral shoot length (final height minus pot height minus mother shoot height) gives the length of a lateral shoot at any given date from pinch to flower. Total plant height on each date is calculated by adding the lateral shoot length plus

Table 1. Values for creating graphs for poinsettias and chrysanthemums.

Relative Development	Relative Height	Time from pinch to flower: 8 week	10 week	12 week	Combined lateral shoot and plant height (inches)
		Days from pinch			
0%	0.00%	0.0	0.0	0.0	7.0
5%	2.32%	2.8	3.5	4.2	7.2
10%	4.88%	5.6	7.0	8.4	7.4
15%	8.87%	8.4	10.5	12.6	7.7
20%	14.38%	11.2	14.0	16.8	8.2
25%	21.22%	14.0	17.5	21.0	8.7
30%	29.05%	16.8	21.0	25.2	9.3
35%	37.41%	19.6	24.5	29.4	10.0
40%	45.88%	22.4	28.0	33.6	10.7
45%	54.08%	25.2	31.5	37.8	11.3
50%	61.75%	28.0	35.0	42.0	11.9
55%	68.71%	30.8	38.5	46.2	12.5
60%	74.90%	33.6	42.0	50.4	13.0
65%	80.29%	36.4	45.5	54.6	13.4
70%	84.91%	39.2	49.0	58.8	13.8
75%	88.84%	42.0	52.5	63.0	14.1
80%	92.13%	44.8	56.0	67.2	14.4
85%	94.88%	47.6	59.5	71.4	14.6
90%	97.15%	50.4	63.0	75.6	14.8
95%	99.02%	53.2	66.5	79.8	14.9
100%	100.00%	56.0	70.0	84.0	15.0

When using Table 1 (left), keep in mind that relative height is expressed as a percent if final length. Days from pinch are shown for plants taking 8, 10, and 12 weeks from pinch to flower. Lateral shoot length is based on a 7-inch tall combined pot and plant height at pinch and final desired height of 15 inches.

the pot height plus the mother shoot height.

Different Cultivars, Different Response Times

If all cultivars of poinsettias and mums flowered in the same number of days, creating the graph would be greatly simplified. This is not the case, as short response group mums may flower in as few as eight weeks from pinch, while poinsettias may take 12 or more weeks to flower from pinch.

Whether the plants flower in eight or 12 weeks, the shape of the curve is the same. However, the curve will be compressed or stretched to reflect the *time* from pinch to flower.

To ensure the horizontal time axis on the graph is correct, the relative time from Table 1 must be multiplied by the total weeks (can also be expressed in days) from pinch to flower in order to get the correct number of weeks (days) from pinch on the horizontal time axis. To complete the graph and make it useful, the days should be converted to actual dates. An example of actual numbers is given in Table 1 and graphed in Figure 3.

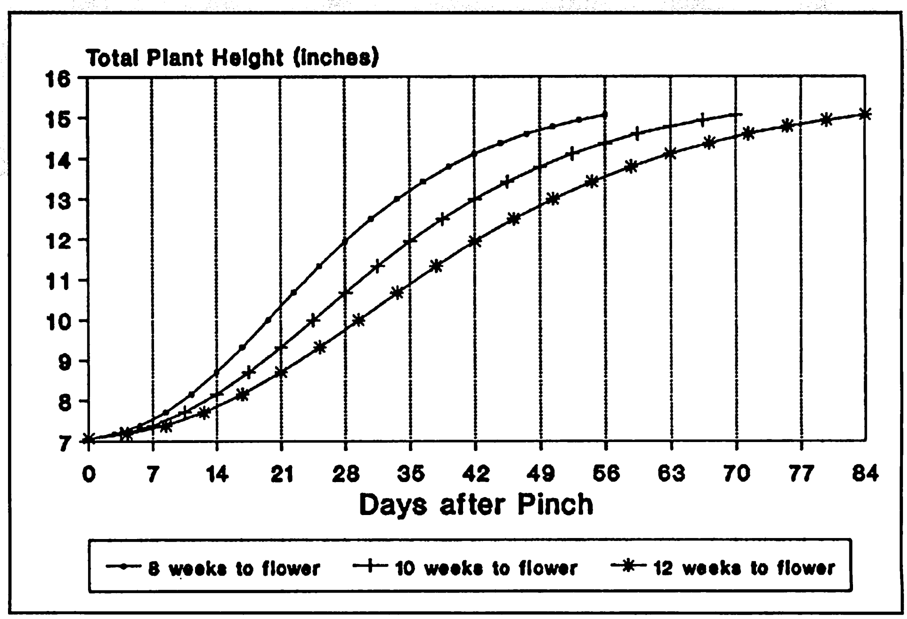


Figure 3. The difference in graphical tracking curves for a plant starting and finishing at the same height, but taking 8, 10, and 12 weeks to flower.

Creating a Graph for Easter Lilies

Creating a graph for Easter lilies is simple compared to poinsettias and mums. It is best created after the plants have emerged. If emergence is uniform, one graph, based on the average date of emergence, may be adequate. However, since lilies typically emerge over a two-week period, two or three graphs are usually more appropriate, especially if the plants are sorted by emergence date into early-, middle-, and late-emerging crops.

Once the emergence date has been determined, visible bud and flowering dates must be chosen. Flowering dates will vary from one to three weeks before Easter depending on the date of Easter and how the crop is marketed. The date of visible bud is 30 to 35 days prior to flowering.

After determining the emergence, visible bud, and flowering dates, the rest is easy. Height at emergence is the height of the pot (normally about 6 inches). Height at visible bud is half of the final plant height. (Remember to subtract the pot height before calculating the visible bud height.) Plot the three points (heights at emergence, visible bud, and flowering) and connect with two straight lines. Two lines are normally plotted to reflect the desired minimum and maximum final plant height.

Selecting Plants to be Measured

The ideal situation would be to have a graph for every plant, but this is not possible. Therefore, selecting representative plants to measure is one of the keys to success with graphical tracking. Selecting the plants to be measured can be more difficult when plants are different heights. Mums of the same cultivar are usually uniform in size. However, this is generally not the case with poinsettias and Easter lilies.

For poinsettias, choose plants by cultivar, pinch date, and size. Representative plants should be selected from within each sorted crop. A graph is plotted for each crop, pot size, pinch date, and cultivar.

Growers producing a large variety of plant sizes may need as many as 10 to 20 different graphs, depending on the number of distinct crops. While this may seem like a lot of graphs, the goal is to precisely produce each crop to desired specifications. A graph for each crop helps accomplish this goal.

It is very difficult to select which plants to measure if short plants are mixed with tall ones or if a single graph is used for plants of different ages. For mums on a rotational schedule, plants of each cultivar should be selected from each rotation. With Easter lilies, it's best to sort by emergence date and to select plants within each sorted crop.

The greatest success with graphical tracking occurs when representative plants are chosen from each greenhouse climatic zone. For example, in houses cooled with fan and pads, plants should be selected from the pad end, from the center of the house, and from the fan end to represent these climatic zones. Individual graphs or lines on a single graph allow plants from each

Figure 4. Jim Mast of Neal Mast Greenhouses, Grand Rapids, MI, shows an effective device for measuring plant heights. Two slots are cut in a piece of cardboard and a yardstick is inserted. The cardboard moves on the yardstick to indicate plant height.

distinct climatic zone to be treated based on their development.

Taking the Measurements

Once the representative plants have been selected, measure plant height preferably twice a week. Monday and Thursday seem to work well for many growers, but other combinations are also acceptable. Two measurements a week are especially important during periods of rapid growth.

Be careful not to mechanically stress (bend) the plants when measuring them. Mechanical stress can reduce stem elongation, and measurements from these plants will not be representative of the rest of the crop. An effective measuring device is shown in Figure 4.

Information From the Graphs

Plotting actual plant height on the graph and comparing it with desired height provides two pieces of information. First, the graph shows how tall the plant is compared to the desired height. Second, the graph shows whether the current rate of growth is fast or slow. You can immediately tell if the plants are shorter or taller than desired for the particular dates the plants are measured.

Information about the rate of shoot elongation is important because a rapidly elongating shoot, even at the desired height, may require a change in DIF and/or growth regulator application to prevent the plants from becoming too tall by the next measurement date. Similarly, a tall plant which is growing slowly may not require any change in DIF or growth regulator applications.

Once you know whether the plants are tall or short and how fast they are elongating, intelligent management decisions can be made. The tools available to slow elongation are DIF and growth regulators. The tool to promote shoot elongation is DIF.

DIF Versus Growth Regulators

There are advantages and disadvantages to using DIF and growth regulators for height control. The advantage to using DIF is two-fold: It reduces the need for growth regulator applications and leaves no chemical residual in the plant when it is transplanted into the finished container.

The major disadvantages to using DIF include the inability to apply different DIFs to different groups of plants in the same greenhouse zone, and the limitations outside climatic conditions put on the ability to deliver a desired DIF. Warm weather, in particular, can prevent a grower from delivering a negative DIF.

Precise control of stem elongation with DIF is impossible when several cultivars or different aged plants are in the same greenhouse zone. Tall and short mum cultivars growing in the same zone as part of a weekly rotation is an example where one DIF must be chosen for all of the plants. Using zero DIF is a good compromise in this situation, and growth regulators can be used as needed on the taller plants and cultivars.

The disadvantage of a growth regulator residual in the plant when it is transplanted can be an advantage under certain circumstances. A plant grown under a negative DIF can elongate very rapidly if day temperature control is lost due to sunny warm weather. In this situation a growth regulator residual could help to hold down growth.

The best height control strategy for many plants is a combination of DIF and growth regulators. The growth regulator provides some buffer against a rapid increase in stem elongation if day temperature control is lost. It also can improve foliage color in some cases, such as B-Nine application to mums. ❑

About the authors: Drs. Royal D. Heins and William H. Carlson are professors, Department of Horticulture, Michigan State University, East Lansing, MI 48824.

Acknowledgement: The research described in this article was funded in part by the American Floral Endowment, the Bedding Plant Foundation, Inc., the Fred C. Gloeckner Foundation, the Ohio Florist Foundation, and several greenhouse growers supportive of Michigan State University floriculture research.

Dr. Meriam Karlsson of the University of Alaska, Dr. John Erwin of the University of Minnesota, and Dr. Robert Berghage of New Mexico State University developed much of the data used in this article while working as research assistants at Michigan State University.

Growers on Graphical Tracking

by DAVID L. KUACK

GRAPHICAL tracking is helping to take the guesswork out of growing. Researchers at Michigan State University have developed growth curves for lilies, poinsettias, and chrysanthemums which can be used to track development. Graphical tracking enables growers to choose a range or "window" of heights in which the plants should be growing. By maintaining plant growth within this window, growers can finish a crop within a specific height range on a specific flowering date.

Although DIF can be used for height control in conjunction with graphical tracking, a grower is not required to use DIF to do graphical tracking. Maintaining plant height within the window can be achieved by the use of DIF in combination with growth regulators or by growth regulators alone.

Need for Different Graphs

According to Dr. Royal Heins, it is unlikely growers could use the same Easter lily graph from year to year simply because the date of Easter changes.

In the case of chrysanthemums, if the response time is different, the growth curve would be different. A graph for a cultivar with an 8-week response time would not be appropriate for a cultivar with a 10-week response time.

A similar situation occurs with poinsettias. Typically the early flowering cultivars are sold earlier than late flowering cultivars. For instance, since there is a seven- to 10-day difference in flowering time for 'Lilo' and 'Gutbier V-14,' a different graph would be needed for each cultivar.

Growers have the option of producing early-, mid-, and late-season poinsettia crops. An early-season crop would be flowered with black cloth, a mid-season crop would flower under natural conditions, and a late-season crop would be delayed from flowering with lights. Therefore, a different graph would be needed for each of these crops.

Heins says some growers have generated their own graphs for Easter lilies. Only three points are required to draw a graph: the date of emergence and height at emergence; the date of visible bud and the height at visible bud; and the date of flowering and the height at flowering.

Although it is possible for growers to manually draw the graphs for poinsettias and mums, Heins recommends that the graphs be computer-generated to ensure the stem elongation curves are accurate. He hopes to eventually develop a computer program that growers could use to generate their own graphs for each of their crops. ❑

Easy To Use

MARK RICHINS of Pineae Greenhouses, Centerville, UT, has been using graphical tracking for two years on Easter lilies.

"Graphical tracking has helped us achieve the desired final height on our lilies," says Richins. "This year we aimed for 18- to 20-inch lilies, and we plan to track our entire poinsettia crop."

When Richins first started using graphical tracking, he measured the height of the lilies twice a week. Now that he is more comfortable with the technique, he usually takes one measurement per week. However, Dr. Heins recommends that two measurements be taken during periods of rapid growth.

Richins designated certain plants as the ones he would measure when the lilies were brought into the greenhouses.

"These lilies were tagged and scattered throughout the entire crop," he says. "I use them to measure both the height and leaf unfolding rate to ensure the plants are developing properly.

"I can look at the measured plants and determine if the plants are too tall or not tall enough. If we encounter weather conditions which promote or deter plant growth, we take the height measurements more often." ❑

Mark Richins of Pineae Greenhouses

Denny Billmaier of Green Circle Growers

Improves Height Control

DENNY BILLMAIER of Green Circle Growers, Oberlin, OH, is sold on graphical tracking for mums.

"We've used graphical tracking for about 2 years and it's been a super tool," says Billmaier. "We've done it on 4-, 4 1/2-, and 6-inch mums. We have a window of 9-10 inches for our 4-inch mums and we grow all of our cultivars to fit into that window.

"We use the same graph for the same pot size, but we have to treat the cultivars differently in order for them to finish at that designated height. Some may require a negative DIF, while others may require more applications or a higher rate of growth regulators. Also, some cultivars are naturally short, so we don't have to do anything to them."

Green Circle grows 10 cultivars in its biweekly 4-inch mum program with an average of three or four rolling tables for each cultivar.

"We measure the height of the plants of each cultivar and rotation twice a week," says Billmeier. "We take an average height for the plants on each bench. From those measurements, we determine whether we use DIF or growth regulators to control height."

Limited Use of DIF

Although he has had success with using DIF for height control, Billmaier depends on it more when the plant height is behind or ahead of schedule.

"With graphical tracking we can maintain much better height control from the start," he says. "We run a constant day and night temperature (zero DIF) to hold the plants at the height we want. If the plants are too short or too tall, then I use a positive or negative DIF. By measuring the height and tracking the growth, we know whether the plants are growing too fast or too slow."

Graphical Tracking Without DIF

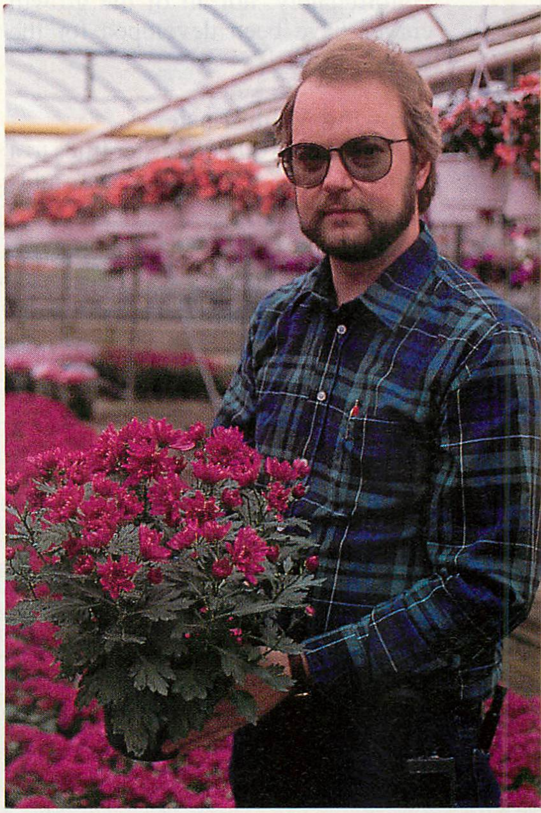
Billmaier emphasizes that growers can use graphical tracking without DIF.

"We're using graphical tracking and growth regulators to maintain the desired height we want," he says. "The amount of growth regulator varies by season due to the change in the weather and the cultivars we're growing, but the method of graphical tracking and measuring the plant height doesn't change. Graphical tracking gives us a window which tells us how much the plants should grow from start to finish."

Easier Marketing

Finishing the plants at the same height also enables Green Circle to better use its marketing tools.

"All of our shipping boxes and marketing devices used for product display have been developed for a finished 4-inch mum of 9-10 inches," adds Billmaier. "Graphical tracking has allowed us to consistently produce the same size crop which has made the marketing of the plants easier and more efficient." ❑



Dave Wiesbrock of Mid-American Growers

Application For Many Crops

DAVE WIESBROCK of Mid-American Growers, Granville, IL, has been very pleased with the height control he has gotten with DIF and graphical tracking on poinsettias, mums, and Easter lilies for the past year.

"DIF has enabled us to cut back on our application of A-Rest on Easter lilies, which can mean a substantial savings," says Wiesbrock. "I don't see any reason why graphical tracking and DIF wouldn't work on other crops, including other types of lilies (Pixies, Asiatics) and bedding plants like seed geraniums. We already use DIF on most of the bedding plants we produce.

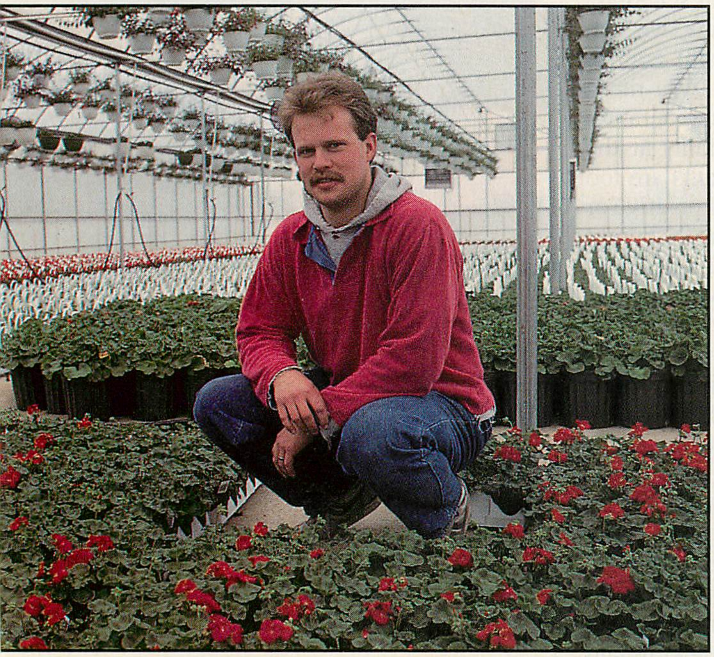
Unfortunately, not all of the growth curves have been developed for the various crops."

Growing Made Easier

"We grow 100,000 Easter lilies to a final height of 17 to 22 inches," adds Wiesbrock. "Without graphical tracking we definitely would have trouble trying to achieve that height."

Wiesbrock usually takes the height measurements every fourth day for the crops he is tracking.

"You have to constantly watch the plants, especially during those periods when they are growing the fastest," he says. "A quick increase in growth could be the result of warm temperatures and/or the plants being in the rapid growth phase of their production cycle. ❑



Randy Uhl of Meiring Greenhouses

Crop and Cultivar Variability

RANDY UHL of Meiring Greenhouses, Carleton, MI, has been using graphical tracking for three years on Easter lilies, poinsettias, and holiday pot mums.

"The first year we did only a few pots, but for the last two years we have really tried to segregate each greenhouse section in order to graphically track plants on each bench," says Uhl. "For instance, of the 40,000 lilies we are producing, we are tracking a total of 20-30 plants — or about two to three plants per bench."

Unlike some growers who need to hold down the height of their lilies, Uhl had to try to increase the height of his lily crop this year.

"We needed more height on the plants in order to reach a final height of 18-23 inches," he says. "We were also concerned with whether the leaves were unfolding fast enough. We went to a positive DIF, maintaining a 75°F day and 63°F night to increase the height of the plants and speed up the rate of leaf unfolding. Prior to going to a positive DIF, we were running the temperatures as close to a zero DIF as possible — 67°-68°F day and night."

Differences in Bulb Size

Uhl explains bulb size may play a key role in rate of development.

"The majority of the bulbs we grow are size 7-8 (measured transverse circumference in inches)," he says. "However, we grew a few 8-9 sized bulbs and these plants developed faster and grew taller than the 7-8s. It was easy to keep the smaller bulb plants within the window because we were trying to increase the height. If we went to the larger sized bulbs, it would take more effort to control plant height."

In addition to generating a graph to track the height of Meiring's lily crop, Dr. Heins also generated a graph to track the rate of leaf unfolding.

"The graph representing the rate of leaf unfolding gives us a guide for comparing what is actually happening with what should be happening," says Uhl. "Growers should remember that just because the plants are within the window in regards to height, it doesn't mean the leaves are unfolding at the proper rate."

New Graph for Each Crop

Uhl says he usually starts with a new graph for each crop since holiday dates (Easter) and cultivars change.

"We are constantly trialing new mum cultivars that have different response times," he says. "The graphs also change for our poinsettia crop depending on the size and condition of the cuttings we start with. We also propagate poinsettia cuttings on different dates so each of the crops produced from these cuttings would require a separate graph."

A Graph for Each Cultivar

Uhl also has new graphs generated for the new poinsettia cultivars he is trialing, including 'Gutbier V-14,' 'Celebrate,' and 'Supjibi,' which have varying rates of development.

"Each cultivar responds differently," he says. "Even though the flowering date may be the same, the size of the cuttings and the pinch date vary. We feel it is best to start with a new graph." ❑

INDEX

GLOSSARY

DIF — The mathematical DIF-ference between the day and night temperature.
  Negative DIF — Occurs when the day temperature is cooler than the night temperature.
  Positive DIF — Occurs when the day temperature is warmer than the night temperature.
  Zero DIF — Occurs when the day temperature and the night temperature are equal.

Flower initiation — Visible organization of flower parts at the stem tip.

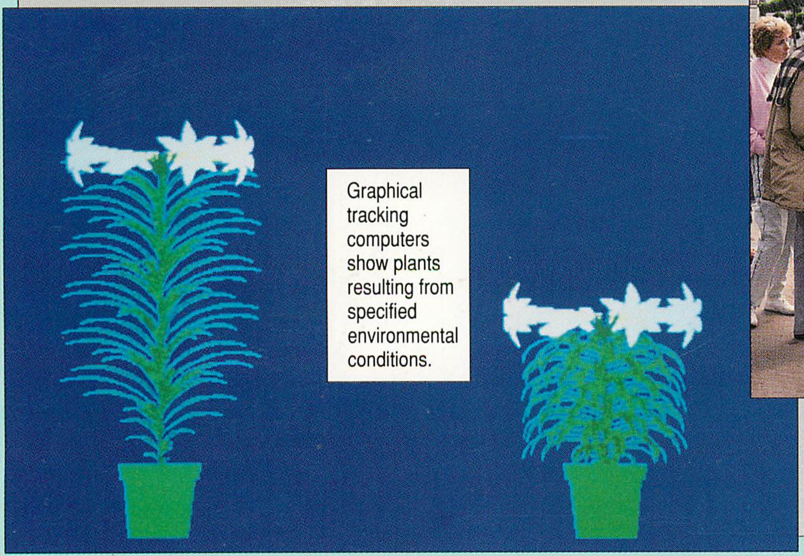
Graphical tracking — A grower management technique whereby the actual height or development of a crop is compared with the desired height or development.

Growth rate — The speed at which a plant progresses through or from one developmental stage to the next. Growth rate includes all plant processes, including internode elongation, leaf unfolding, and flower induction, initiation, and development.

Plant development — The series of processes (including leaf unfolding, internode elongation, and flower initiation) from the start of growth until the death of a plant.

Temperature dip — A drop in greenhouse temperatures for two hours immediately at sunrise, which has been found to be more effective in reducing internode elongation than reducing temperatures later in the day. Also called shock treatment.

It's happening at
MICHIGAN STATE
UNIVERSITY,
a center of floriculture
teaching, extension
and research.



For further information on educational opportunities, extension information or research activities, contact:

Dr. William H . Carlson,
240 Plant & Soil Science Building
Michigan State University
East Lansing, MI 48824
517-355-5178 • Fax: 517/353-0890