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TEMPERATURE EFFECTS ON BEDDING PLANT GROWTH

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Introduction

This chapter will discuss what is known about temperature effects on bedding-plant development rate and morphology. Recent attempts to develop bedding-plant temperature tolerance will also be discussed. Lastly, how you as a grower can utilize this new information in your bedding plant program will be summarized.

What Determines Plant Temperature?

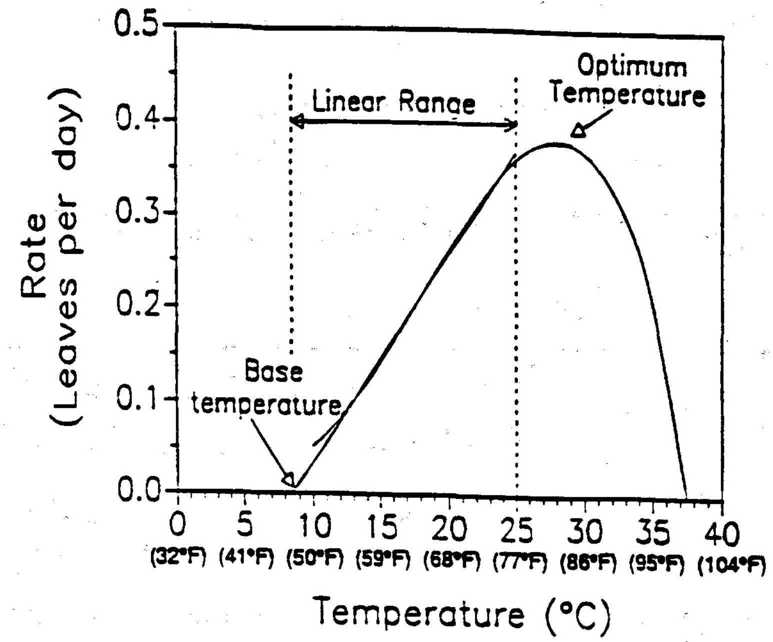
The temperature of a plant at any given time is a summation of a number of individual factors that have direct and indirect effects on heating or cooling of a plant. For instance, a plant can be directly heated by the surrounding air through conduction and/or convection. Conduction is the direct heating of the leaf by the air. Convection is a change in temperature brought about by a change in the density of the air around a leaf, resulting in a flow of air. Convection can be passive or forced change in temperature as in the case of wind. In contrast to conduction and convection, chemical energy released during metabolism or by conversion of sunlight to heat can indirectly increase plant temperature.

Plants lose energy through convection and/or conduction, ,when leaf temperature is higher than the surrounding air, by the latent heat of water evaporation from the leaf by transpiration, uptake of water cooler than the plant tissue, and/or emission of long-wave radiation from the plant itself.

The primary mechanism through which a plant can control its temperature is through transpiration. The evaporation of water requires energy. The use of that energy during evaporation of water from a leaf surface results in a drop in leaf temperature. When transpiring heavily, a leaf can actually dissipate as much as 50% of the energy it absorbs.

All plants respond to temperature similarly.

Figure 1. *Typical temperature response curve. Note the base temperature, linear range, maximum rate and decrease in rate at high temperatures.*



Everyone wants to know the 'optimal temperature' for each bedding plant. The optimal temperature for a given plant depends on a number of factors.

Interestingly, leaf-shape studies conducted through comparisons of different shapes of copper plates show that heat loss is greatest when the plate shape is elongated or lobed. Heat loss was least when the plate shape was circular which could explain the predominance of lobed and/or elongated leaves in warmer climates where heat loss is crucial for growth. In contrast, studies on leaf size show that large-leafed species have greater difficulty dissipating energy than small-leafed species. This fact is the probable basis for the prevalence of small leafed species in desert regions.

Optimal Temperatures

All plants respond to temperature similarly (Figure 1). No growth occurs below a certain temperature. This temperature is often referred to as the 'base temperature'. Above the base temperature, growth increases proportionally as temperature increases until an 'optimal temperature' is reached. At this point the rate of growth is maximized. As temperature increases above the 'optimal temperature', plant growth decreases. Base temperatures vary from 32-50°F. Optimal temperatures for plant growth vary from 65-85°F.

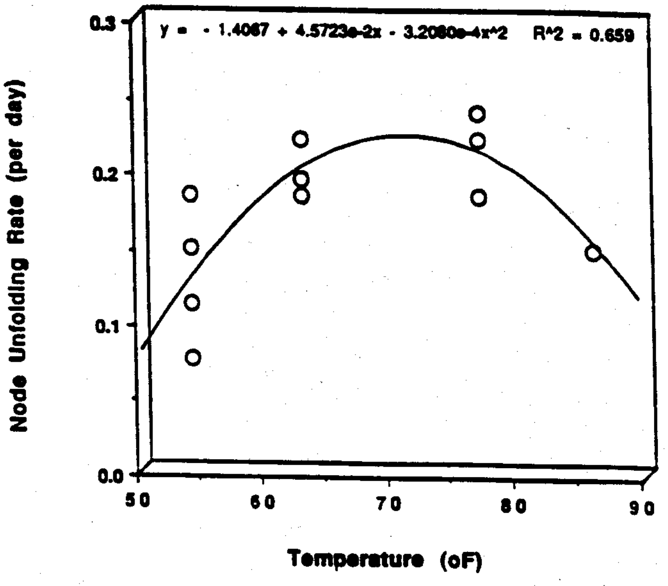
The definition of plant growth can vary greatly from grower to grower.

What's the Optimal Temperature of My Crop? Everyone wants to know the 'optimal temperature' for each bedding plant. The optimal temperature for a given plant depends on a number of factors. First, the optimal temperature for plant growth varies according to how you define plant growth. In most cases, growers define plant growth as an increase in mass, height, or earliness in flowering. The optimal temperature for plant growth also varies depending on 1) the plant species, 2) the stage of a crop's development and 3) the time of a day/night cycle.

Definition of Plant Growth. The definition of plant growth can vary greatly from grower to grower. A cutting producer defines plant growth primarily in terms of leaf unfolding, which leads to greater cutting production. In contrast, a wholesale grower who finishes a crop often defines growth in terms of total plant and flower mass and earliness of flowering. The optimal temperature for plant growth varies considerably between these two growers because of what they are trying to achieve in their crop production cycle. For instance, an optimal day/night temperature setting for New Guinea impatiens cutting production is 76° day and 65°F night temperatures. This temperature regime will result in a high rate of leaf unfolding, longer internodes, thick stem calibre and greater partitioning of carbon to the stems. In contrast, the optimum temperature for finishing New Guinea impatiens is constant 68°F. Constant 68°F in comparison to other temperature regimes will result in reduced plant height, large flower size and carbon partitioning to flowers rather than stems.

Impact of Plant Species. Optimal temperatures for growth vary with plant species. Species that originate from warmer climates tend to have higher temperature optima than those that originate from cooler or temperate climates. For example, fuchsia, dianthus and primula prefer cooler temperatures, i.e. 60-70°F. *Bellis*, or English daisy, will actually die if night temperatures reach 75°F. In contrast to cool-loving species, those that originate from warmer climates have warmer optimal temperatures. For example, zinnia, vinca and New Guinea impatiens have higher optimal temperatures, i.e. 70-80°F.

Figure 2. *The effect of average daily temperature on zonal geranium cv 'Veronica' node unfolding rate when grown under temperatures ranging from 54 to 86°F.*



The optimal temperature for plant growth varies at different stages of plant development.

Stage of Plant Development. The optimal temperature for plant growth varies at different stages of plant development. The optimal temperature for increase in plant mass tends to decrease as a plant ages. For instance, the optimal night temperature for vegetative development of pepper decreases from 86°F to 48°F as the plant matures. Similarly, the optimal temperature for rapid development of chrysanthemum decreases from 70° to 67°F as the plant matures.

The optimal temperature for growth often varies with the time of day.

Time During a Day/Night Cycle. The optimal temperature for growth often varies with the time of day. Higher day temperatures tend to promote higher rates of photosynthesis. Cooler night temperatures tend to decrease respiration, or carbohydrate depletion. Together, warmer days and cooler nights tend to promote high gains in plant mass or weight. For instance, tomato growth, as determined by weight gain, is greatest when plants are grown at 76°F day and 68°F night temperatures. Higher day and cooler night temperatures also promote high dry weight gain in pea, chrysanthemum, pepper and lily.

In most cases, growers are interested in promoting different aspects of plant growth at different times in the production cycle. For instance, a geranium grower who propagates and finishes geraniums is interested in cutting production during the fall and winter. During early spring, after rooting the cutting, interest shifts to increasing the above-ground plant mass. Later in spring, interest is primarily focused on controlling plant height and encouraging flowering. The types of growth that are desirable vary between these stages and have different temperature optima. For this reason a grower must understand how temperature affects each aspect of plant development to produce a highly profitable bedding-plant crop of high quality.

Rate of Plant Vegetative Development

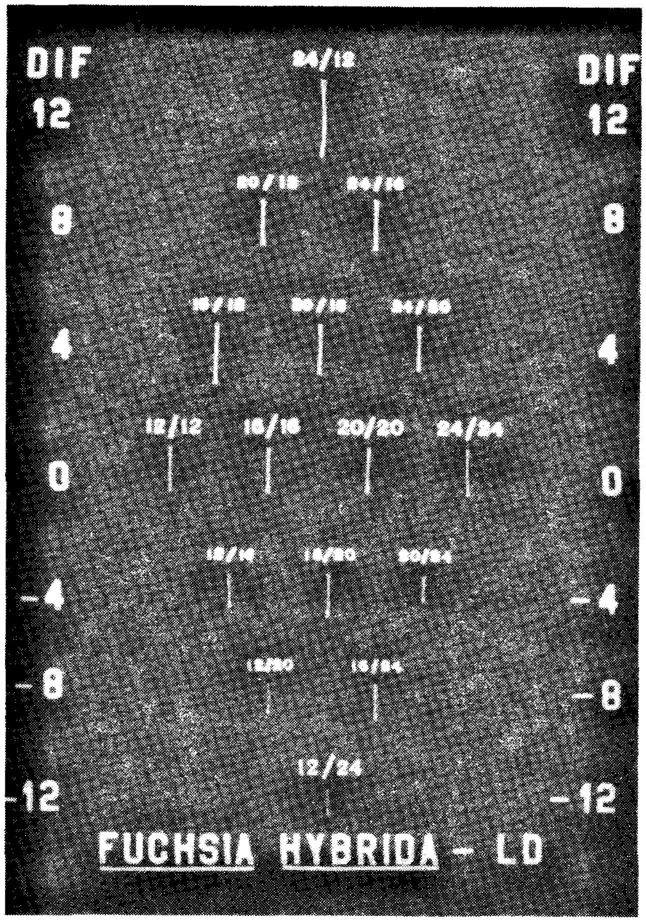
The rate of vegetative development is often quantified by determining the leaf unfolding rate of a crop.

The rate of vegetative development is often quantified by determining the leaf unfolding rate of a crop. High leaf unfolding rates demonstrate rapid development. In general, leaf unfolding rate has a similar temperature-response curve to that of plant growth. Leaf unfolding rate has a base temperature that usually ranges from 40-45°F. Leaf unfolding increases nearly proportionately as temperature increases until an optimum is reached. Leaf unfolding rate then decreases if temperature increases above the optimum (Figure 2).

Leaf unfolding rate then decreases if temperature increases above the optimum.

Most greenhouse production during the early part of the season occurs at temperatures in the linear portion of a leaf unfolding curve. Later in the season, temperatures during the day can routinely be above the optimal temperature for leaf unfolding.

Figure 3. *As DIF varies from 0 (in either a positive or negative direction), internode elongation decreases on Fuchsia x hybrida cv 'Dollar Princess'.*



Leaf unfolding rate is proportional to the average daily temperature plants are grown under when temperatures are maintained in the linear range.

Leaf unfolding rate models are available for a number of bedding-plant species.

Leaf unfolding rate is proportional to the average daily temperature plants are grown under when temperatures are maintained in the linear range. Therefore, daily leaf unfolding rates can be determined by calculating the average daily temperature and solving for 'x' in a linear equation. If temperatures exceed the linear range, it will be necessary to calculate leaf unfolding rates on a short-term basis, i.e. every 2 hours, then adding 2-hour rates to determine the actual leaf unfolding rate per day.

Leaf unfolding rate models are available for a number of bedding-plant species. For instance, leaf unfolding rate models have been developed for petunias, begonias, geraniums, hibiscus, vinca, etc. Common equations for temperature effects on leaf unfolding of the above mentioned crops were used to calculate the leaf unfolding rate per day when plants were grown at a variety of different temperatures.

We can use this information to determine the average temperature which we need to maintain to insure that our crop is at the desired stage of development when it is to be marketed. For instance, from past years you have determined that the leaf number on your 'standard' geranium crop which is 14. Cuttings arrive this year with five leaves. In other words, you need to unfold nine leaves in your greenhouse. Calculate the daily leaf unfolding rate

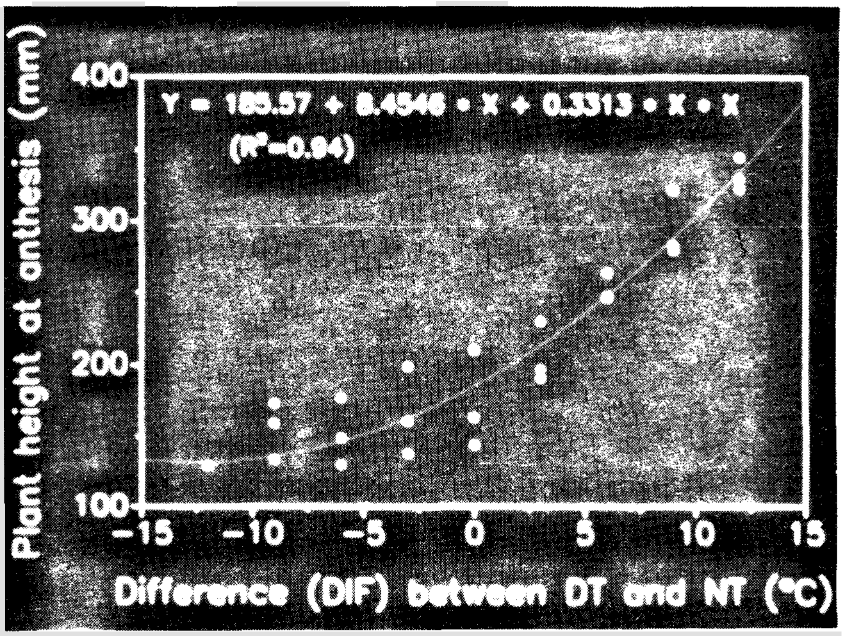


Figure 4. *The effect of increasing DIF on poinsettia cv 'Dark Red Annette Hegg' plant height at flowering.*

Table 1. *The effect of increasing or decreasing temperature at different times during the day on snapdragon, salvia, geranium and petunia internode length. Plants were grown at constant 68°F except for the designated pulse periods.*

Pulse Period	Pulse Temperature (°F) 63		74
0900-1300			
Snapdragon	1.30		2.36
Saliva	1.69		2.66
Geranium	3.72		5.20
Petunia	7.07		6.70
1300-1700			
Snapdragon	1.20		1.59
Salvia	1.65		2.46
Geranium	3.72		5.87
Petunia	5.55		7.15
Controls	**63/68**	**68/68**	**74/68**
Snapdragon	1.22	---	1.62
Salvia	1.19	1.95	3.49
Geranium	3.22	4.45	5.75
Petunia	5.80	6.90	7.75

Plant appearance is based on a number of plant attributes that define the overall quality of a plant.

you will need to maintain to have you crop come in on schedule. To do this simply divide the number of leaves that you need to unfold by the number of days until marketing. To insure proper timing use an equation or graph to find the approximate average daily temperature you will need to maintain.

Temperature Effects on Plant Appearance

Plant appearance is based on a number of plant attributes that define the overall quality of a plant. Plant attributes that are commonly evaluated include height, leaf size, branch number and flower number and size. Temperature affects these features of plant appearance in different ways.

Plant Height. Plant height is determined by stem length. Stem length is based on the number and length of internodes. The number of internodes is dependent on the average daily temperature as described above in the leaf unfolding section. In contrast to leaf and/or node number, internode length on every bedding plant which we have studied is dependent on how temperature is delivered during a day/night cycle.

DIF. Internode length increases as day temperature increases relative to night temperature on all bedding plants. In other words, internode length increases as the difference between day and night temperature increases. A term that is used to describe the difference between day and night temperature is DIF (day temp. - night temp. = DIF).

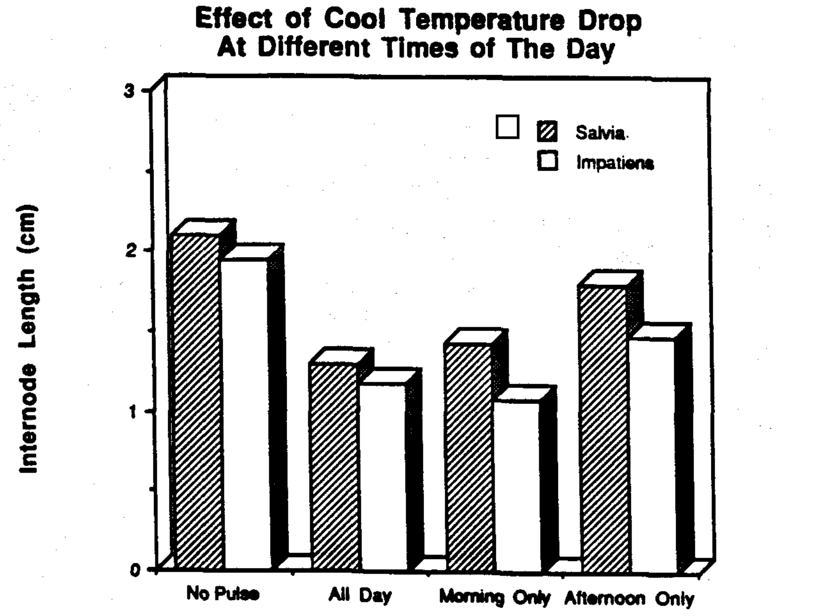
Internode length increases as day temperature increases relative to night temperature on all bedding plants.

Internode elongation increases as DIF increases (Figure 3). It is also important to realize that the response to DIF decreases as DIF decreases (Figure 4). In other words, there is a greater decrease in stem elongation when DIF changes from +10° to 0°F (higher day than night to constant temperatures) than from 0°F to -10°F (constant temperatures to a cooler day than night). In general, stem elongation can be reduced by 1/3 by going from a higher day than night to constant day and night temperature regime.

Environmental Factors Affecting Response to DIF. The response of stem elongation to DIF is greater as day length decreases and light intensity

Plant stem elongation is most sensitive to temperature during the first 2-3 hours of the morning.

Figure 5. *The effect of cool temperature drops at different times of the day on internode length.*



increases. Therefore, response to DIF is greater under short days than long days. For instance, if you are growing a crop under natural day length the plant response to DIF will be greater in January than April under full-sun conditions. Similarly, you will get a greater response to DIF on sunny days than cloudy days. A lack of response to DIF in European greenhouses is probably do to low-light conditions which are common during the fall, late winter and early spring months.

Most growers find that utilizing the 'temperature drop' to be the most practical aspect of using temperature to control plant height.

Temperature Drop or Pulse. Plant stem elongation is most sensitive to temperature during the first 2-3 hours of the morning. Dropping temperatures during the first 2-3 hours of the day can result in almost as much reduction in stem elongation as if temperatures were reduced all day (Table 1; Figure 5). Conversely, increasing temperature can stimulate stem elongation significantly (Table 1). Keep temperatures cool for as long in the day as possible. In addition, do not let temperatures increase immediately in the morning.

Most growers find that utilizing the 'temperature drop' to be the most practical aspect of using temperature to control plant height. Often controlling temperatures during the latter part of a day is more difficult than controlling temperatures during the morning. Commonly growers will drop temperatures to 45-50°F for the first 2-3 hours on a bedding plant crop.

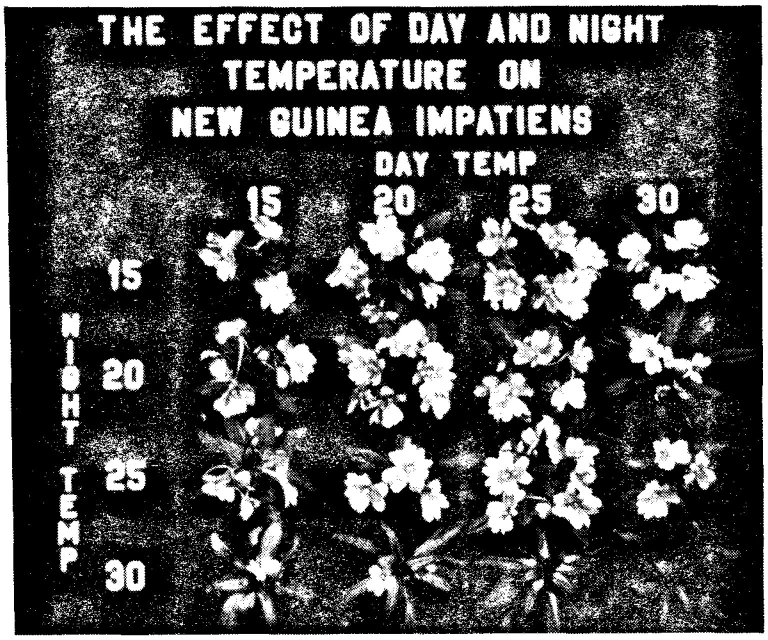
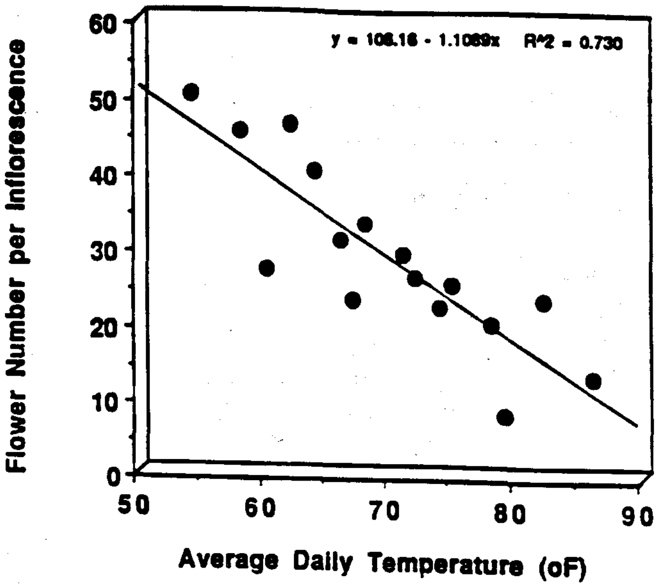


Figure 6. *The effect of day and night temperature on New Guinea impatiens cv 'Mimas' grown at temperatures ranging from 63°F to 86°F (15 =36°F, 20=68°F, 25=72°F and 30=86°F.*

Figure 7. *The effect of average daily temperature on the number of flowers per inflorescence on zonal geranium cv 'Veronica' at anthesis.*



Dropping temperatures for 2-3 hours does not greatly affect average daily temperature in most cases. Therefore, your cropping schedule will not be greatly delayed using this technique compared to if you cool temperatures all day.

Interaction Between Temperature Drop and Environment and Watering. The reduction in stem elongation due to a temperature drop is greatest when the drop is rapid, occurs at sunrise, and light intensity is high. Alternative ways to drop temperatures can be to simply overhead water plants with cold water at sunrise. The cool water and evaporation reduces plant temperature as a drop in air temperature would. Utilizing fans to drop temperatures quickly is also beneficial.

Stem Size

Stem calibre or thickness is important for stem strength and in cutting propagation. In general, thicker stemmed cuttings tend to root more readily. Stem calibre, thickness and/or dry weight is responsive to average daily temperature and DIF. In general, stem calibre increases as average daily temperature decreases and as DIF increases.

Stem calibre is related to stem mass where an increase in stem mass results in an increase in stem diameter or calibre. Geranium peduncle dry weight increased from 0.044 to 0.252 grams (+572%) as average daily temperature decreased from 86 to 54°F. In contrast to geraniums, New Guinea impatiens stem dry weight was maximum when plants were grown with an average daily temperature of 76°F. Stem dry weight decreased as average daily temperature deviated from 76°F. New Guinea impatiens stem dry weight also increased from 0.04 to 1.43 grams as DIF increased from -30 to +30°F.

Leaf Size, Thickness, and Color

As with stem calibre or mass, leaf size and dry weight partitioning are affected by average daily temperature and DIF. Optimal temperatures for leaf size for bedding plants are often between 68 and 76°F. For instance, gerbera leaf area increased under long and short days as temperature approached 76°F. Similarly, New Guinea impatiens leaf dry weight has an optimal temperature of 76°F. In addition, leaf dry weight increased from 2.26 to 4.41 grams as DIF increased from -30 to +30°F. Cucumber leaf expansion has an optimal temperature of 68°F. Leaf area on many species is also affected by DIF. For instance, leaf area of fuchsia and marigold increases as DIF increases when temperature ranges from 50 to 86°F.

Leaf color or 'greenness' increases as DIF increases. More severe chlorosis can occur when day temperatures are less than night temperatures. Leaf chlorosis induced by temperature is generally temporary. In contrast to leaf 'greenness', leaf zonation on geraniums increases as the average daily temperature which plants are grown under decreases.

Flower Initiation

There are optimal temperatures for flower initiation on all crops. Temperatures which are higher or lower than the optimal temperature can inhibit flowering completely, or reduce flower number. For instance, the optimal temperature for fuchsia flower initiation is 68°F. As tempera-

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Stem calibre or thickness is important for stem strength and in cutting propagation.

As with stem calibre or mass, leaf size and dry weight partitioning are affected by average daily temperature and DIF.

There are optimal temperatures for flower initiation on all crops.

Table 2. *The effect of day and night temperature on the time to flower from the initiation of long days and flower number per node of Fuchsia x hybrida 'Dollar Princess'. The photoperiod was 8 hours. Long days were delivered with the 8 hour photoperiod with night interruption lighting from 2200-0200 hour.*

Night Temperature (°F)		Day Temperature (°F) 54	61	68	75
54					
	Time to Flower	82	75	70	73
	Flowers/Node	2	4	6	4
61					
	Time to Flower	58	52	51	66
	Flowers/Node	6	6	5	5
68					
	Time to Flower	61	53	53	59
	Flowers/Node	6	5	5	5
75					
	Time to Flower	58	53	60	67
	Flowers/Node	4	5	4	2

Temperature sensitivity of flower initiation can vary during a day/night cycle.

tures deviates from 68°F flower number per node is reduced and flower initiation is delayed (Table 2).

Temperature sensitivity of flower initiation can vary during a day/night cycle. Sensitivity of chrysanthemum and poinsettia flower initiation to night temperatures is common knowledge and is often referred to as 'heat delay'. However, recent research has shown that flower initiation of a number of significant bedding plant crops are sensitive to temperatures during the day only, during the day and night or during the night only.

New Guinea impatiens and geraniums are examples of crops which are day and night temperature sensitive.

Day and Night Temperature Sensitive. New Guinea impatiens and geraniums are examples of crops which are day and night temperature sensitive. New Guinea impatiens flower number decreases dramatically when day or night temperature exceeds 76°F or drops below 63°F (Figure 6).

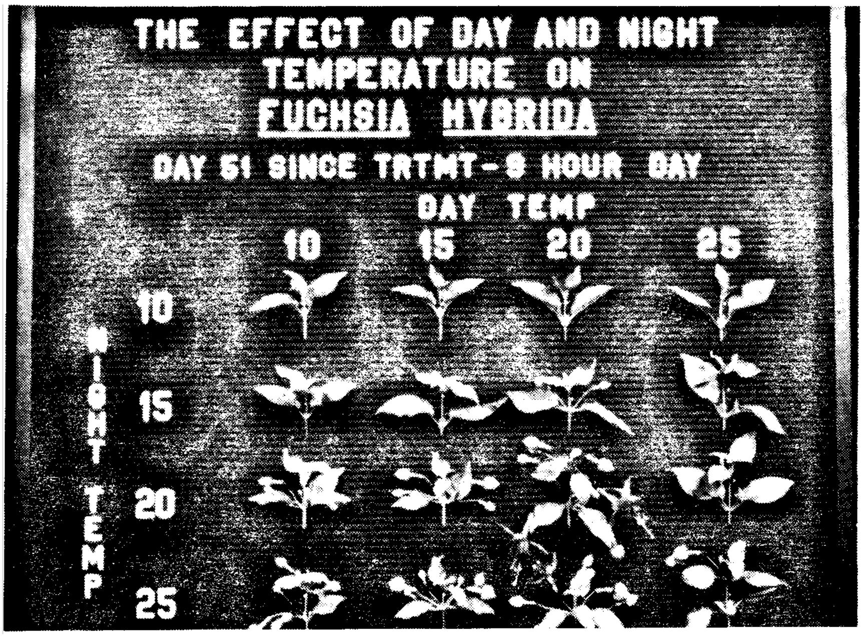

Figure 8. *The effect of day and night temperature on Fuchsia hybrida.*

Table 3. *The effect of day and night temperature, and average daily temperature on Regal geranium cv 'Fantasy' time to flower. Numbers indicate the length of time from the end of the cooling treatment to anthesis.*

Night Temperature (°F)	Day Temperature (°F) 54	63	76	86
54	72	69	90	---
63	60	---	---	---
76	69	---	---	---
86	---	---	---	---

In contrast to New Guinea impatiens, zonal geranium flower number decreases as temperatures increase from 54°F (Figure 7). Zonal geranium cv 'Veronica' flower number per inflorescence decreased from 52 to 23 flowers as temperature increased from 54 to 76°F. Similarly, 'Sooner Red' hybrid seed geranium flower number decreased from 40 to 27 flowers per inflorescence as temperature increased from 50 to 90°F.

'Lilipot Red' dianthus appear to have an optimal temperature for flower number of 68 day/63°F night. Day or night temperatures deviating from this temperature regime reduced flowering. Other crops which are sensitive to both day and night temperature are chrysanthemum, schlumbergera and gerbera. Optimal temperatures for flower initiation of all of these crops is approximately 68°F.

It is unclear, however, if there is a lack of flower initiation or simply abortion of flowers which have initiated. For instance, all flower buds abort prior to flowering after an inductive treatment on Regal geraniums when the average daily temperature exceeds 61°F; the response to temperature is purely a flower bud abortion effect.

Day Temperature Sensitive. Only fuchsia have been identified as day temperature sensitive plants. Fuchsia flower initiation is inhibited when day temperatures exceed 68°F (Figure 8). Once plants have been initiated, flower number per node drops from 6 to 2 when day temperatures exceed 68°F or drop below 61°F (Table 2). Extended periods of temperatures in excess of 76°F eliminate flowering completely.

Only fuchsia have been identified as day temperature sensitive plants.

Night Temperature Sensitive. African marigolds are night temperature sensitive. Night temperatures in excess of 74°F will inhibit flowering. Similarly, poinsettia is extremely night temperature sensitive. Night temperatures in excess of 74°F will delay flowering considerably.

Differential Sensitivity During a Day or Night Cycle. The sensitivity of plant flower initiation to temperature can vary within a day and/or night cycle. Sensitivity of short day plants to high temperatures during the night is greatest 8 hours

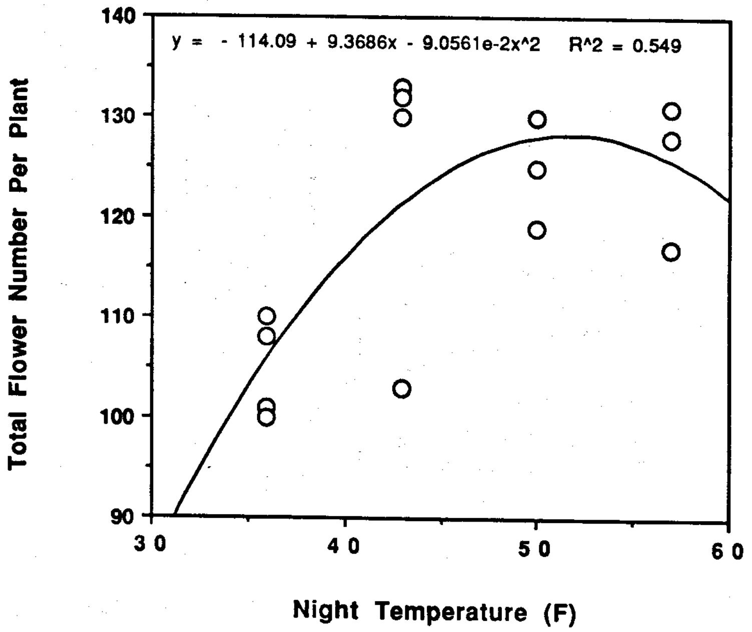

Figure 9. *The effect of night temperature on total flower number per plant of Regal geraniums.*

African marigolds are night temperature sensitive. Night temperatures in excess of 74°F will inhibit flowering.

The sensitivity of plant flower initiation to temperature can vary within a day and/or night cycle.

after the start of the night period. Preliminary research on geranium suggests that geranium flowering is sensitive to high temperatures primarily at the end of the day.

Thermoinduction. Some bedding plants can be induced to flower using temperature alone. The best example of this is primula. Primula can be induced to flower when temperatures are maintained below 63°F.

Similarly, Regal geranium flower induction can be hastened by a cooling treatment. Traditional treatments suggested that plant receive a 4-6 week cooling period at 45°F to have maximal flowering and reduced flowering time. However, recent research suggests the optimal temperature for a cooling treatment for Regal geraniums appears to be 50°F. Specifically, as night temperature increases to 50°F during vernalization, the number of flower buds in an inflorescence increases (Figure 9).

The effect of temperature on flower size varies among plant species.

Flower Development

Flower Bud Development. Both flower bud development and abortion are influenced by the average daily temperature plants are grown under (Figure 10). Both 'Red Elite' and 'Sooner Red' hybrid seed geranium flower bud development rate increases as average daily temperature increases up to approximately 75°F. Interestingly, many species including gerbera, Easter lily, fuchsia, and New Guinea impatiens flower bud development rate increases as temperature increases until 75°F. Increasing temperature above 75°F does not hasten flowering. In contrast to the above species, fibrous begonia cv 'Scarlanda' bud development rate was primarily affected by night temperature.

Commercial breeding programs throughout the United States have begun to emphasize breeding for high temperature tolerance of many bedding plants.

As stated above, although flower induction of regal geraniums is complete after a cooling treatment, all flowers abort if the average daily temperature after induction exceeds 61°F (Table 3).

Flower Size. The effect of temperature on flower size varies among plant species. On those species which are sensitive to temperature, the optimal temperature for flower size tends to be less than those for leaf unfolding and/or leaf expansion. For instance, the optimal temperature for leaf size on New Guinea impatiens is 76°F, whereas, the optimal temperature for flower size is 68°F. Flower size on zonal geraniums decreases slightly as temperature increases from 54 to 86°F. In other words, temperature had relatively little affect on the size of an individual flower of a zonal geranium. In contrast, flower diameter of 'Sooner Red' hybrid seed geranium has an optimal temperature of approximately 65-68°F.

Breeding for Temperature Tolerance

Commercial breeding programs throughout the United States have begun to emphasize breeding for high temperature tolerance of many bedding plants. Often bedding plants are grown in areas that are exposed to full sun and/or near pavement and road surfaces which can heat the plants.

It is, however, critical that a breeder understand whether a plant is sensitive to day, night, or day and night with respect to flower initiation. It is also possible, for instance, that many plants do not flower because of flower bud abortion rather than a lack of flower bud initiation

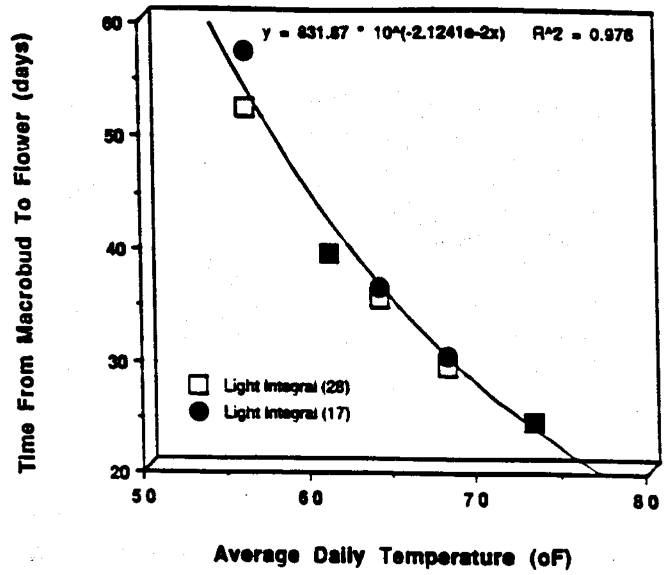

Figure 10. *The effect of average daily temperature on the time from macrobud to flower on the hybrid seed geranium cv 'Red Elite'.*

Currently, efforts are underway at the University of Minnesota to breed for high temperature tolerance in New Guinea impatiens and fuchsia. Dick Craig's program at The Pennsylvania State University has been breeding from heat tolerance in regal geraniums for a number of years.

Growing For Quality Using Temperature

It is evident from the above information that different aspects of plant growth can respond differently to temperature at different times in plant development. It is critical that you, as a grower, understand how temperature affects each aspect of plant development. Often different species of bedding plants which have vastly different temperature optima are grown side by side on a bench. The best example of this is when geranium (cool temperature loving) is grown side by side with New Guinea impatiens (warm temperature loving).

It is critical that a breeder understand whether a plant is sensitive to day, night, or day and night with respect to flower initiation.

Currently, efforts are underway at the University of Minnesota to breed for high temperature tolerance in New Guinea impatiens and fuchsia.