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Temperature Effects on Floriculture Crops and Energy Consumption

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The high cost of energy this spring is forcing many greenhouse growers in colder climates to re-evaluate different aspects of their production strategies. When we had a surge in fuel prices in 2000-01, *Greenhouse Grower* magazine surveyed growers about what they did differently in response to the increased fuel costs. According to their September 2001 issue, the highest percentage (22%) of respondents lowered their growing temperature. Other growers increased the insulation of their greenhouses (15%), started production later (13%), and consolidated production (12%).

Based on this data, about one-third of the greenhouse operations in the United States either lowered their greenhouse temperature, delayed the start of their production, or both. How do those actions influence crop timing? Did the growers actually save energy? And, as a result of those changes, did growers meet their target marketing and shipping dates? This article will discuss these concepts and provide insight into the answers to these questions.

The Effects of Temperature on Plants

Temperature is the primary factor that controls how fast (or slow) a plant develops. Generally, the warmer the temperature, the faster a plant grows. It's analogous to how fast you drive your car to get to work. The faster you drive, the earlier you arrive at work. Similarly, the warmer you grow your crops, the quicker they will grow and become marketable. Therefore, if you lower the greenhouse temperature, plants will take longer to become marketable. This applies to plugs, flats, potted crops, hanging baskets, and any other size of plant or container.

Another important concept to understand is "temperature integration." This term describes how plants respond to temperature over a period of time. Simply put, the rate of plant development is dependant upon the average daily temperature from the time you plant the crop. This is a very simple but powerful concept. Plants respond to the temperature constantly; they grow faster as temperature increases, and grow slower as temperature decreases. The exception to this rule is when cool-season crops are grown very warm. At some high temperature these plants begin to experience stress and the rate of crop development begins to decrease.

What is the implication of temperature integration? If your day and night are each 12 hours long, then if you lower your night temperature without increasing your day temperature the same amount, your average daily temperature will decrease. Thus, cooler nights without warmer days will increase the time it takes for your crop to become shippable or transplantable. If your night temperature settings are longer than 12 hours, then you need to offset the shorter day temperature setpoint even more so that your 24-hour average temperature stays the same.

Crops Respond to Temperature Differently

As temperature decreases, there is some temperature at which a plant stops developing. This temperature is called the "base temperature," and it varies from crop to crop. For example, the base temperature for seed petunia is about 39°F (4°C), which means that at or below this temperature, petunias essentially stop growing. For seed vinca (*Catharanthus sp*), the base temperature is much higher, around 50°F (10°C). Experienced growers can often predict which crops have a low base temperature because they are usually grown cooler than plants that have a high base temperature.

We rarely want to grow plants at or near the base temperature because plant development is so slow. One of the few times when a growing temperature near the base temperature is desirable is when you want to hold plants – such as when plants are beginning to flower but you're not able to ship them. Another example is when perennials or bulbs are being vernalized or provided with cooling treatments.

During the winter and spring, floriculture crops are often grown about 20°F to 30°F (11°C to 17°C) higher than their base temperatures. As temperature increases above the base temperature, plants grow faster and faster. For example, the effect of temperature on crop timing of petunia and vinca is illustrated in Figure 1. Lowering the temperature by 5°F has a somewhat small effect at warm temperatures, and has a larger effect at cooler temperatures. For example, lowering the average daily temperature by 5°F from 65°F to 60°F delays a petunia crop (from seed) by about 13 days, and lowering the temperature from 60°F to 55°F delays petunia by 22 days. The effect of lowering the temperature on crop timing also depends on the plant species. For example, lowering the temperature from 65°F to 60°F increases the time to flower of vinca (from a plug) by about 30 days – much longer than the delay in petunia with the same temperature decrease.

Cold-Tolerant and Cold-Sensitive Crops

Plants respond differently to temperature partly because they have different base temperatures. Plants with a base temperature of 39°F (4°C) or lower can be called "cold-tolerant plants" and those with a base temperature of 46°F (8°C) or higher can be called "cold sensitive plants." We categorize plants by their base temperature because they differ in how they respond to lowering the greenhouse temperature; generally, cold-sensitive plants are more responsive to lowering the greenhouse temperature than cold-tolerant species. So, if you are determined to lower your greenhouse temperature setpoint, you'll likely delay crop timing more with coldsensitive crops. See Table 1 for a list of plants categorized by their base temperatures. Ideally, crops with different base temperatures should be grown in separate greenhouses with different temperature setpoints.

The effect of temperature on crop timing of some popular bedding plants can be found in Table 2. There are other factors that influence crop timing, including photoperiod and the average daily light integral. With my colleagues Ryan Warner and Art Cameron, we're continuing work with bedding plants and herbaceous perennials to further understand how plants respond to temperature so that more refined growing temperatures can be recommended.

Does Lowering Temperature Save Fuel?

This is the $10,000 question – in some cases, quite literally. We know that by reducing the average daily temperature, we increase the production time of a crop. To finish crops on the same date as in years past, growers can begin with a more mature crop (such as transplanting from a 128-cell plug instead of a 588-cell seedling), or they need to transplant earlier in the year. If you transplant earlier in the year, chances are you're going to open up greenhouses earlier in the year. Because it will be colder outside, energy consumption for heating is relatively high. A simple question follows: is it economical to increase the production time to compensate for a lower average greenhouse temperature?

During the winter and early spring, it can be more energy-intensive to grow crops at cooler temperatures than to open up the greenhouse later and use a warmer growing temperature. A lower temperature setpoint requires less heating, which translates into less fuel consumption per month. However, a temperature reduction also increases crop timing, which means plants are in the greenhouse longer. A longer production time has several negative consequences, including:

- overhead expenses (cost per ft^2 per week) are greater for that crop
- the crop takes longer to finish, so you will turn fewer crops per year
- a longer crop time means that you will have to heat the crop longer and possibly open up a greenhouse earlier when it is colder outside.

Hiroshi Shimizu at the University of Ibaraki in Japan developed a sophisticated model to predict how much energy is consumed to heat a greenhouse to produce a crop. The simulations are complex and depend on environmental factors (outdoor temperature, light levels, and wind speed), numerous greenhouse factors (glazing type, use of thermal curtain, insulation, etc.), the crop grown, and the greenhouse temperature setpoint. Figure 2 illustrates the predicted energy consumption to heat a crop in Michigan with different finish dates and three temperature setpoints. This simulation was based on Michigan weather data, a greenhouse crop with a base temperature of 41°F, and several assumptions for a "typical" doublepoly greenhouse. From winter until mid-summer, the model predicts that the total amount of energy used to heat a crop (from transplant to flowering) actually *increased* as the growing temperature decreased. In other words, it was more expensive to heat a crop planted earlier in the year and grown at a cool temperature compared to opening a greenhouse later and using a higher temperature setpoint. The opposite was true for fall crops; an earlier planting date and a lower greenhouse temperature consumed the least amount of energy.

There are other consequences to growing crops in a cool greenhouse. One concern is that plants take longer to dry out, so they stay wet longer. Also, because cooler air holds less moisture than warmer air, the relative humidity can be higher in a cool greenhouse. Pathogens can be more problematic when crops are kept moist and when the humidity is high.

Temperature Effects on Plant Quality

There is one major benefit to growing crops relatively cool in the winter and spring, when light is limiting in northern latitudes. Crops grown cool take longer to flower, so they have a longer period of time to harvest light. Because of this, many plants (especially coldtolerant crops) are of higher quality when grown at moderately cool temperatures. When ready for transplant, plugs grown at cool temperatures often have thicker stems, better rooting, and greater branching. Similarly, finish crops grown cool can have more branching and produce more, larger flowers. However, there are floriculture crops (such as hibiscus) that do not perform well at cool temperatures. For such tropical plants, plant quality is highest when grown at a moderately warm temperature.

Therefore, there is often a trade-off between high quality crops and crop timing. Cooler temperatures produce higher quality plants, but they take longer to reach maturity, and energy consumption per crop can be higher. Crops grown at warm temperatures develop faster and thus have shorter crops times and require less energy for heating, but the quality of plants is often not as high. If a grower cannot get a higher price for a higher quality crop, then there is little incentive to grow cool.

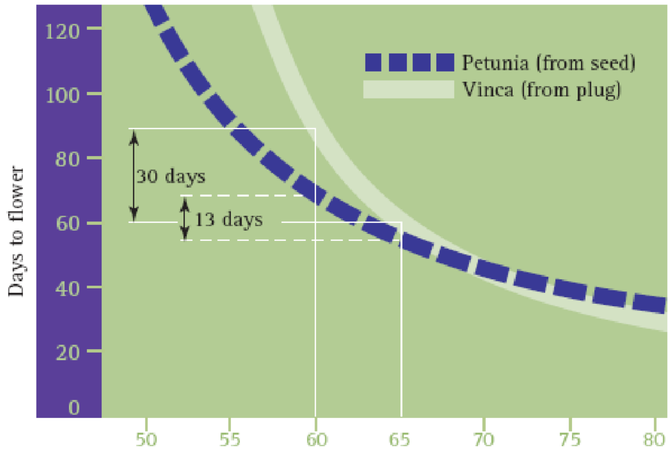

Figure 1. *The effect of temperature on time to flower of petunia from seed and vinca from a small plug. When temperature is decreased, there is a larger delay in flowering for plants with a high base temperature (vinca) compared to plants with a lower base temperature (petunia).*

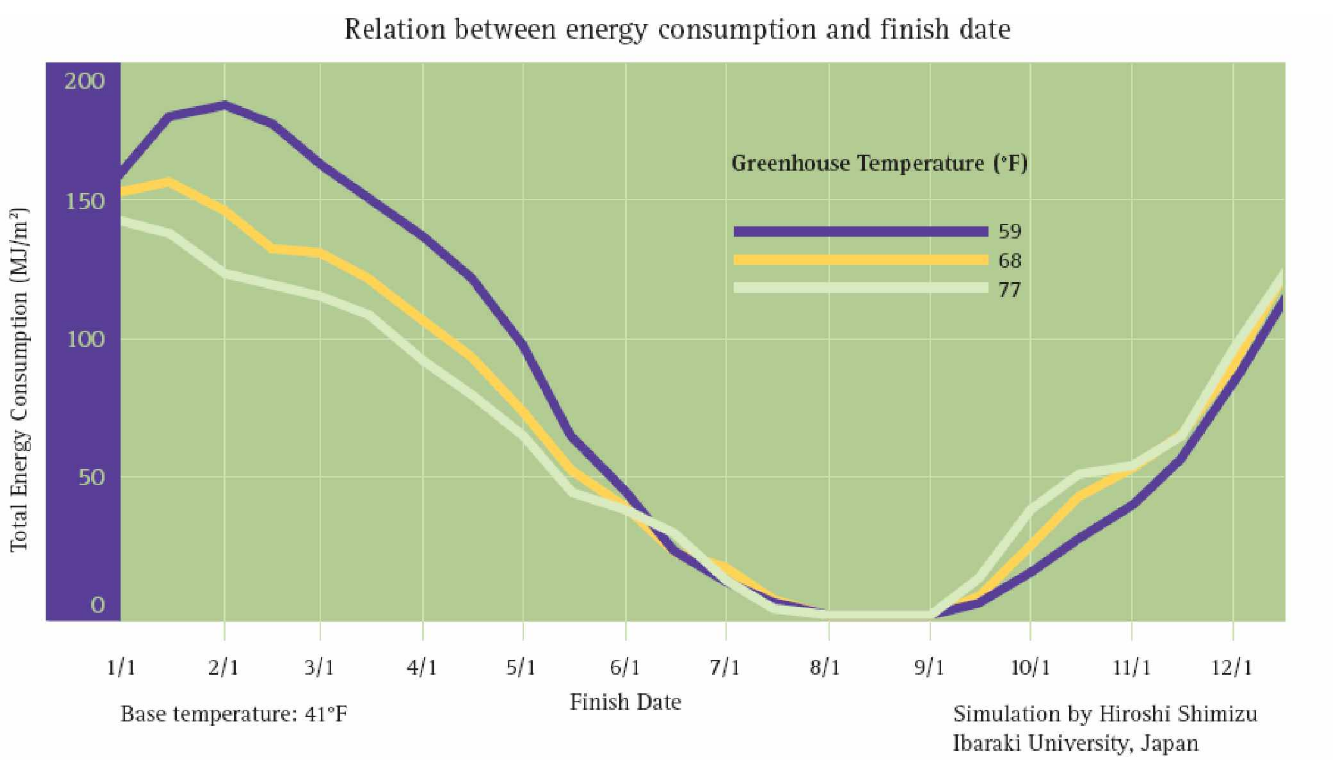

Figure 2. *The estimated amount of energy required to produce a crop at different growing temperatures throughout the year in Michigan. This simulation indicates that the total amount of energy consumed to produce a flowering crop increased as growing temperature decreased from winter through mid-summer.*

Table 1. Plants can be categorized by their base temperature, which is the temperature at or below which crops stop developing. Plants with a base temperature of 39°F (4°C) or lower can be called "cold-tolerant" crops, and those with a base temperature of 46°F (8°C) or higher can be called "cold-sensitive" crops. Information based on research at Michigan State University and published research-based articles.

Plants with a low base temperature (39°F or lower)	Plants with a moderate base temperature (40 - 45°F)	Plants with a high base temperature (46°F or higher)
Ageratum	Calibrachoa	African violet
Alyssum	Coreopsis	Angelonia
Campanula	Dahlia	Banana
Cineraria	Impatiens (seed)	Begonia (fibrous)
Diascia	Salvia	Blue salvia
Easter lily		Caladium
Gaillardia		Celosia
Leucanthemum		Gazania
Marigold (French)		Hibiscus
Nemesia		New Guinea impatiens
Petunia		Pepper
Rudbeckia		Phalaenopsis orchid
Scabiosa		Poinsettia
Snapdragon		Purple fountain grass
Thanksgiving cactus		Rose
Viola		Vinca

Table 2. The effect of temperature on days to flowering of four bedding plants grown from a 288-cell plug. Plants were grown under an average daily light integral of 5.5 $mol \cdot m^{-2} \cdot d^{-1}$, which is typical of early spring conditions in northern greenhouses.

	Average daily temperature (°F)		
Plant	63	68	73
Celosia	52	44	37
Impatiens	31	26	22
Marigold	32	27	24
Salvia	39	33	27