Using greenhouse temperature for plant control

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The first article gave some examples of 'tools' that a greenhouse grower can use for manipulating plant growth and controlling yield. Temperature is one of the main control tools. Examples were presented of effects of temperature on photosynthesis, respiration, and distribution of sugars. This article touches on some other effects of temperature. First we look at the principles of plant growth.

Plant growth in a nutshell
Plant growth starts with *light interception* that fuels *photosynthesis*. Photosynthesis is uptake of CO2 gas and production of sugars (*assimilates*) in the leaves. A small part of the sugars is burnt for plant maintenance, in a process called *respiration*. The remaining sugars are transported to all plant parts, including roots, stem, head, flower, fruit. This is called *distribution of assimilates*. Inside the plant parts, the sugars are *transformed* to other compounds such as proteins, etc., and are combined with excessive amounts of *water* to form plant tissues. Then new leaves and new flower buds or flower trusses appear. This is called *development*. A higher rate of development means that the leaves and flowers come out faster. After the new organs have appeared, their *cells stretch* and therefore the stems, leaves, buds, flowers, fruit and roots grow in size. This is all required to reach the end goal: harvest of produce.

Effect of temperature (day, night, 24-hour)
Greenhouse growers can use temperature for controlling plant growth. Temperature affects all plant processes, either strongly or moderately, either directly or indirectly. Temperature can do different things at different times of the day. Therefore we distinguish: (a) day temperature, (b) night temperature and (c) 24-hour temperature. We can also see temperature effects in even shorter periods of time, e.g. in the pre-night (the so-called pre-night temperature drop, see previous issue), early night, late night, early morning. Growers can use 'dif', which is the difference between day and night temperature. Table 1 lists the main plant processes and growth factors.

24-hour temperature
The main general effects of overall temperature include (a) development, (b) assimilate distribution, (c) fruit ripening, (d) respiration. Together this also influences the internal plant balance: whether plants are too generative or too vegetative. The main effects are:

(a) The average temperature over 24 hours stimulates the rate of development, which is the rate of appearance of new leaves and flowers. At higher 24-hour temperature, more leaves and more trusses appear per month. This effect is well known in many crops.
(b) Higher temperature seems to favour distribution of sugars to the fruit. So in warmer conditions relatively more sugars are put into fruit and less in leaves.
(c) Higher temperature speeds up fruit ripening. It also stimulates earliness of production. The first harvest is some days earlier at higher temperature.
(d) The rate of respiration, which is burning assimilates for maintenance, increases slightly with higher temperature. Therefore if the temperature gets considerably higher, less sugar will be available for growth and production. This decreases fruit size and may also reduce production.

Day-time temperature

Day-time temperature has a very strong effect on cell expansion. High temperature stimulates cell stretching, and this causes length growth of the stem and increase of leaf area.
Night-time temperature has very little effect on cell expansion and on length growth. Night temperature is just part of the 24-hour temperature, and contributes to the 24-hour temperature effects mentioned above.
An experiment was done with tomatoes growing in different compartments, one with 26 °C day temperature and 16 °C night temperature (26/16 day/night), and the other compartment with the reverse temperature (16/26 day/night). The plants that received warmer days grew much faster and became more than twice as tall and had 18% larger leaf area than the plant receiving cooler days. This was due to far more cell expansion. Interestingly, both treatments got to the same number of leaves, as this depends on the development rate and this depends on the average temperature over 24 hours (the 24 hour temperature was about the same in both treatments).
Since high day-time temperature stimulates growth, we can apply low day-time temperature for keeping plants short and compact. This works for all crops, but is often applied to young plants and ornamental pot plants. To keep plants compact, bring the night and day temperature closer, or even make day temperature lower than night temperature.

Temperature effect in the vegetative stage

In the very early stage, or vegetative stage of the plant, the only growth parameter is leaf growth. In an experiment with eight tomato varieties, seedlings grown at 21 °C got many more leaves than seedlings grown at 18 °C. This is because high average 24-hour temperature stimulates the rate of leaf appearance. However, the leaves stayed smaller at 21 °C, and hence the total leaf area was about the same in both treatments. In these very young plants, the higher temperature was not able to increase the leaf area.

Temperature effect on fruit growth

In the productive stage, things become more complicated. The rates of both leaf and truss development are faster at higher temperature. In the same experiment with eight tomato varieties (but now in the generative stage), the appearance of leaves and trusses was 25% faster at 21 °C than at 18 °C.
Once the fruit were set, the plants at higher temperature started to put more energy into their trusses. This is because higher temperature stimulates sugar distribution to the fruit. It is due to plant hormones coming from the seed in the fruit; they pull the assimilates to the fruit.
Also, high temperature speeds up fruit growth and development. The period from fruit set to harvest was 56 days at 18 °C, and was reduced to 46 days at 21 °C. This is 18% faster. The fruit grown at higher temperature stayed smaller though. Due to the fast development rate, there are more trusses on the plants. They all compete with each other for sugars, and hence all fruit stay smaller.

Temperature effect in productive stage

In the generative (productive) stage, leaves and fruit compete. At higher temperature, more assimilates go to the fruit. Hence less assimilates are available for leaf area growth. Also, leaf picking starts earlier in the warmer conditions (21 °C) than in the cooler conditions (18 °C). In the experiment with eight tomato cultivars, the result was 25% less leaf area at 21 °C than at 18 °C.
In summary, plants grown at higher temperature (21 °C) produce fruit faster: you get more fruit but they are smaller than from plants grown at lower temperature (18 °C). Which temperature gives the best production was very much depending on the variety. So in tomatoes, if you want to grow at higher temperature, you must keep less fruit per truss, or you will end up with smaller fruit. Vice-versa, if you want smaller tomato fruit you can grow at higher temperature.

Summary
Temperature affects most processes in plants in different ways, some very subtle. We distinguish between day temperature, night temperature, 24-hour, and short-term temperature effects such as pre-night temperature drop.
High 24-hour temperature generally stimulates the rate of development, speeds up fruit ripening, stimulates earliness of production, and seems to favour distribution of sugars to the fruit. However, high 24-hour temperature also increases the respiration (burning of assimilates) and decreases the fruit size and may reduce fruit production,
High day-time temperature very strongly stimulates stretching: it stimulates cell expansion and this causes length growth of the stem and increase of leaf area. Night temperature does not stimulate stretching, but is just part of the 24-hour temperature, and contributes to the 24-hour effects mentioned above.
Temperature (and all other factors too!) strongly influence the internal plant balance: whether plants are too generative or too vegetative. Following articles will look further into all this.

***Table 1**. Simplified overview of processes involved in plant growth & production, and influences of the main growing factors. +++ strong influence, ++ moderate influence, + weak influence. Effects can be direct or indirect. Indications only, different crops may have different responses.*

Plant process	Tempe-rature	Light or radiation	Humidity	CO2 Conc.	Water & CF
Photosynthesis (uptake of CO2 and formation of sugars)	+	+ + +	+	+ + +	
Respiration (burning sugars for plant maintenance)	+ + +				
Uptake of water and nutrients	+	+ + +	+ + +	+	+ + +
Transpiration (loss of water through the leaves)	+	+ + +	+ + +	+	+ +
Development (appearance of new leaves and flowers)	+ + +				
Flowering	+ +	+ +		+	
Fruit set	+ +	+ +	+ +	+	
Dry matter distribution (spreading sugars to all plant parts)	+ + +				
Formation of plant tissue (conversion of sugars, incorporation of water)	+ +		+		+ +
Stretching (cells and organs getting larger)	+ + +	+ +	+		+
Fruit ripening	+ + +	+ +			

Notes:
- Valid for temperature range 15 - 30 °C. Under 15 °C and over 30 °C processes get disturbed.
- Temperature control can be for other reasons e.g. disease prevention, energy efficiency.