Growing and Energy Conservation©

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INTRODUCTION

As energy costs rise, resistance to it becoming a larger proportion of production cost increase. One option to consider in this battle is altering thermostat settings during initial crop growth stages early in the growing season.

The challenge is to reduce energy requirements in greenhouse crop production while maintaining quality and on-time delivery. Two concepts will be discussed with respect to greenhouse heating set points. These are Q_{10} factors (Q_{10} temperature coefficient is a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C) during seed germination and DIF (refers to the difference between day and night time temperatures) during active growth.

GROWING AND ENERGY

A plant is packaged energy. Like any organism it consumes energy to grow, protect, maintain, and reproduce itself. In native habitats, plant species evolve to accomplish this within the seasonal time frame utilizing "free" energy supplied by the sun. In nature success is defined as being there.

In the nursery we impose size, time, uniformity, and developmental requirements. Impatience costs money. Supplementary energy input, in the form of light and heat purchased during winter and early spring is what costs. Establishment of uniformity early in a crop cycle is perhaps the most energy intensive. If establishing uniformity at lower temperatures is required, then high-seed vigor is extremely important because it facilitates seed germination at a wider range of temperatures. Multiple sowing (per cell) and thinning may be a viable strategy depending on seed cost and availability. Germinating at low temperatures generally results in reduced uniformity that can be partly or wholly re-established at thinning.

Energy forms critical to photosynthesis and "growing" are light and heat. Light drives the photosynthetic process and heat warms the photosynthetic machinery so it can operate. Heat also encourages convection around plants thereby replenishing CO_2 supplies and "driving" transpiration. Outside, during the natural growing season, these energy forms are abundantly available and in approximately the correct proportions. However, in a greenhouse during the winter they seldom are. The challenge is to supplement and balance them in such a way that "growth" occurs. Optimum settings are growth-stage dependent.

HEAT AND GERMINATION

Respiration of stored seed reserves provides the energy that fuels germination. Respiration rate increases with temperature. The goal is fast, uniform, disease-free germination. Many things affect this but let's concentrate on seed temperature. Given healthy, stratified seed at appropriate moisture content Figure 1 depicts its response to germination temperature. If ~82% germination is the cutoff for

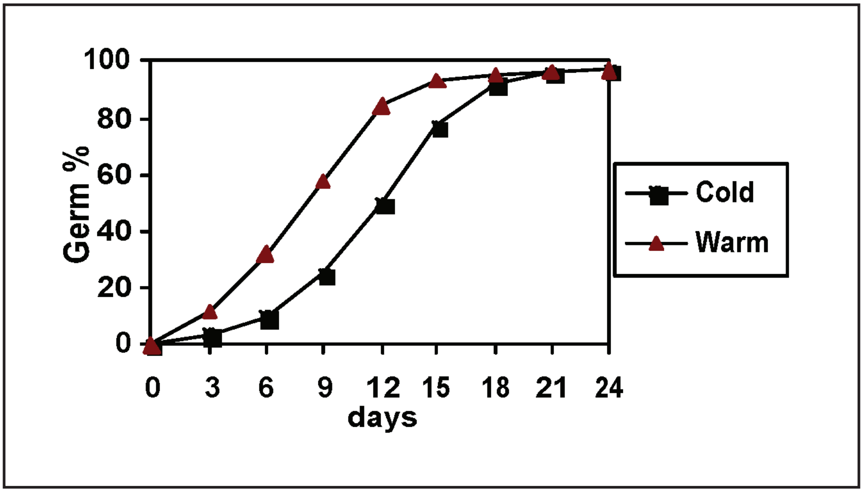

Figure 1. Cumulative germination percentage over time (24 days) at different temperatures.

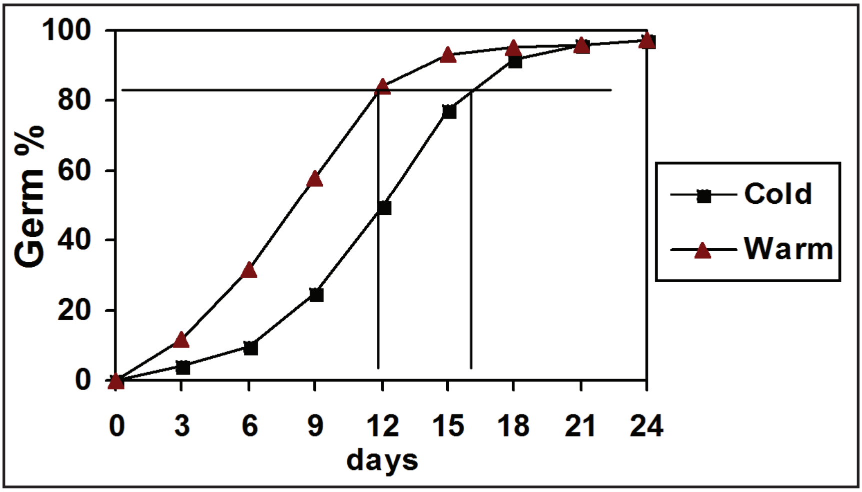

Figure 2. Effect of temperature on time to reach threshold germination percentage (82%).

switching from a "germination" to "growing" environment, then the "warm" regime allows compression of the germination phase by 5 days (Fig. 2).

Shortening the germination phase... does it pay? Figure 3 depicts in general the rate at which energy is supplied to a seedling, and how it accumulates energy over the course of its first growing season. Please realize that no heat energy supplied ends up inside the seedling as stored chemical bond energy. All the energy that constitutes a seedling it has to capture and store itself. We cannot "pump it up." Heat energy supplied only helps facilitate conversion of light to chemical bond energy by warming the production machinery, allowing it to work more quickly and efficiently. A germinating seedling, once showing green, is a small solar panel.

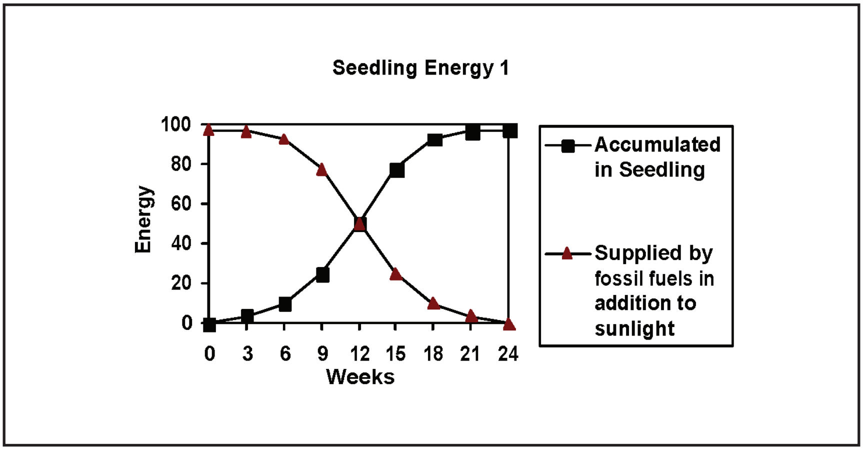

Figure 3. The rate at which energy is supplied to a seedling and how it accumulates energy over the course of its first growing season.

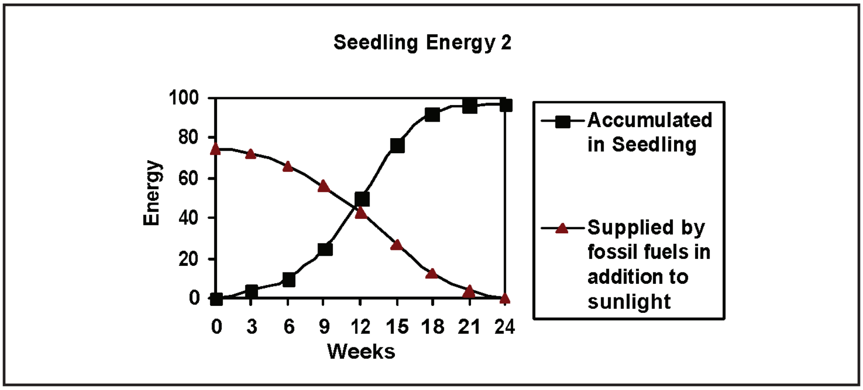

Figure 4. Energy accumulation in seedlings vs. energy supplied to optimize growth.

The large up-front fuel expense is due to the inefficient way heat is supplied to germinating seed. A handful of seed is distributed into a huge, virtually uninsulated, volume of air termed a greenhouse, which is subsequently heated. Is this worth the cost? Are there other ways to realize the objective?

Can we reduce energy use or increase energy use efficiency as in Figs. 4 or 5?

Q_{10}.

Assume a seed with stratification complete, and moisture, oxygen, and carbohydrate reserves not limiting. The rate at which biochemical processes proceed within a seed depends on seed temperature. The function that describes how the rate of a biochemical reaction changes with changing temperature is called the "Q_{10} factor." Over a specified range, it describes how the reaction rate changes per 10 °C interval.

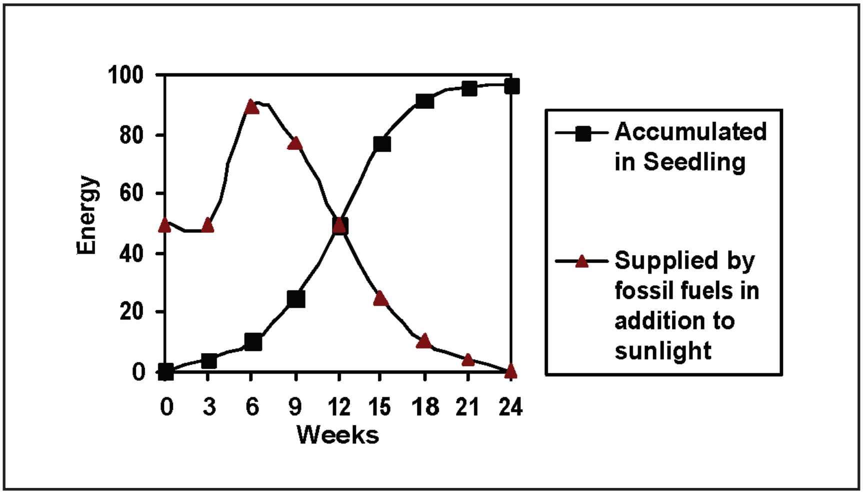

Figure 5. Energy accumulation in seedlings vs. energy supplied to optimize growth.

Between 5 °C and 35 °C for respiration in plants the Q_{10} factor is approximately 2. This is an exponential relationship. It means that over the specified temperature range, a 10 °C rise affects a doubling of the respiration rate (Fig. 6). From the onset of germination until green is showing, respiration rate = germination rate!!

Practically speaking, raising seed temperature from 5 to 15, 10 to 20, or 15 to 25 °C in each case doubles respiration/germination rate. Hence, going from 5 to 25 °C quadruples it! Keep this in mind when choosing germination and growing temperature regimes. At a higher initial temperature where respiration/germination rate is higher to begin with, a certain Celsius increase instills a much larger response than at lower temperatures, where initial rates are lower.

Obviously huge gains in germination speed and uniformity can be made by raising germination temperature into the mid-high twenties Celsius. But still the question…does it pay, especially at high per unit energy costs?

The cost of raising growing facility temperature is a function of the area of the structure, covering heat loss value, inside humidity level, air exchanges per unit time, and outside temperature/wind/precipitation conditions.

Combining Figs. 6 and 7 gives the following relationship shown in Fig. 8.

Figure 8 shows that with each successive increase in greenhouse temperature, the return on the heating investment increases (in terms of increased germination speed). In the above scenario (6-mil single poly at -10 °C outside temperature), the first unit of energy is consumed to achieve a greenhouse temperature of 5 °C. Respiration (germination) rate is at 1. Adding a 2nd unit of energy brings greenhouse temperature to 20 °C and instills a respiration rate of 3. Adding a 3rd unit of energy brings greenhouse temperature to 35 °C and raises respiration/germination rate to 9 times the rate at 5 °C! In other words, 3 days at 5 °C will give the same germination result as 1 day at 20 °C (seed temperature, not just greenhouse air temperature), saving 2 days of heating time at 5 °C = saving 33% on the fuel bill to attain the same level of germination.

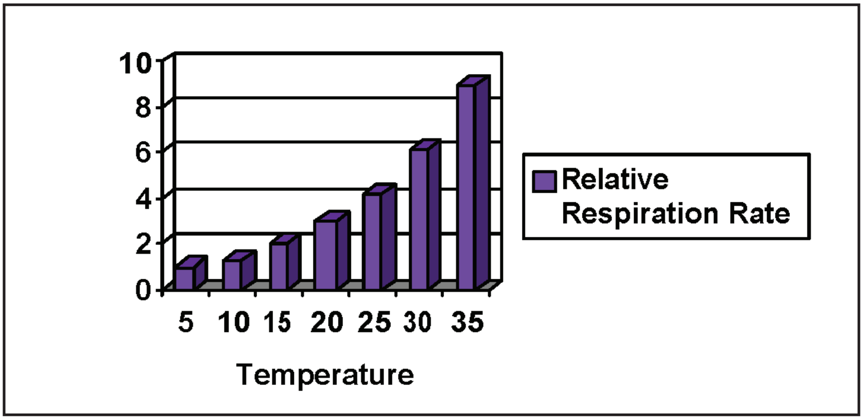

Figure 6. Q_{10} = 2 for plant respiration (5 - 35 °C).

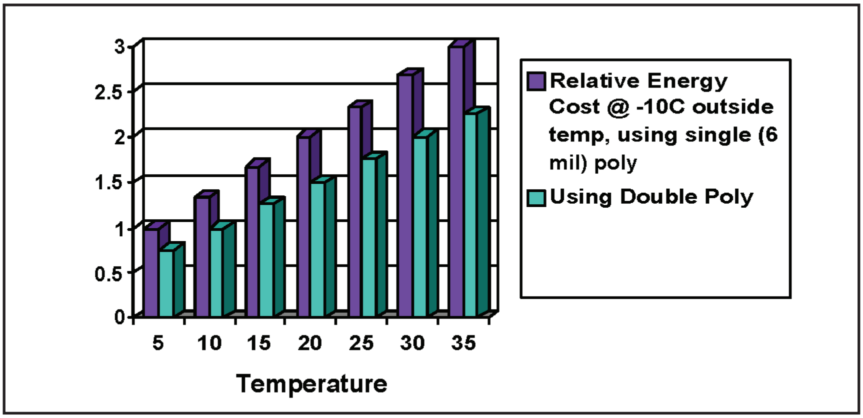

Figure 7. Greenhouse heating costs increase in a linear, not exponential fashion.

The bottom line is that it pays to increase germination temperature. In fact, the higher the per-unit energy cost, the more it pays! You have to spend money to make money.

DIF: AFTER GERMINATION

The difference between day and night time temperatures is referred to as DIF. Regular growth is an extension of germination; hence, temperatures that promote growth will promote germination. However, for many plants optimum germination temperatures are somewhat higher than optimum growing temperatures. This is due to the fact that respiring storage reserves in seed generates energy requirements for germination-type growth, which involves primarily a reactivation and "unfolding" of previously developed systems and structures. Photosynthesizing organs and "machinery" have maintenance energy requirements, which increase exponentially with temperature. This leads to the concept of "net growth," which equals gross photosynthetic production minus respiratory maintenance requirements.

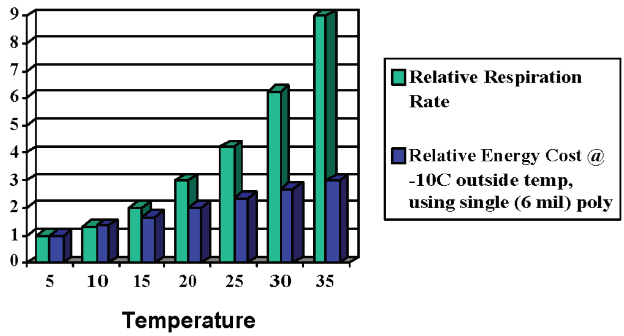

Figure 8. Q_{10} vs. Greenhouse Heating.

NET PHOTOSYNTHESIS

Energy conversion is the concept. In a greenhouse during winter/spring, with help from stored pre-historic solar energy (natural gas, propane, coal) converted to heat, we make it possible to convert current solar energy (sunlight) to chemical bond energy through the process of photosynthesis (Fig. 9).

- Photosynthesis (PS) only occurs in the presence of light (and carbon dioxide).
- Net photosynthesis = photosynthesis minus respiration.
- Net photosynthesis is positive if photosynthesis > respiration.
- Net photosynthesis is negative if photosynthesis < respiration.
- Twenty-four-hour net photosynthesis is positive if daytime net PS exceeds nighttime respiration losses.
- Annual net photosynthesis is positive if growing season net PS exceeds non-growing season respiratory losses.
- Once seed reserves are consumed, young plants start out with virtually no stored energy reserves.
- Net photosynthesis has a lower temperature optimum under low light. Fewer storage reserves are being generated for future use (night, etc.) (Fig. 10).
- Dark period temperature needs to allow for reallocation of resources generated during the day (physical growth, maturation, and reorganization within the plant) while minimizing respiratory losses (Fig. 11).
- Good net PS days can support warmer nights and may require them to process additional photosynthetic products generated during the preceding day.
- Poor net PS days do not require and cannot support long and/or warm nights, especially in plants with low stored energy reserves (small, young plants are more vulnerable).
- A poor net PS day can be bright and very hot, bright and very cold, dull and warm, etc.

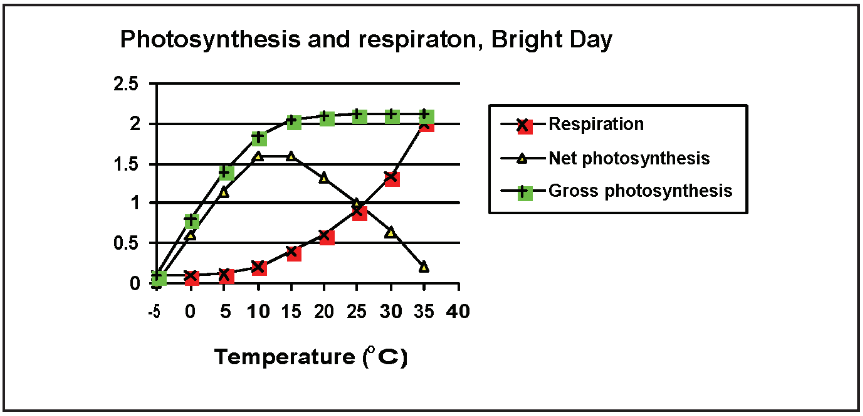

Figure 9. Gross photosynthesis - respiration = net photosynthesis. Respiration of stored carbohydrate (energy) reserves drive "growth."

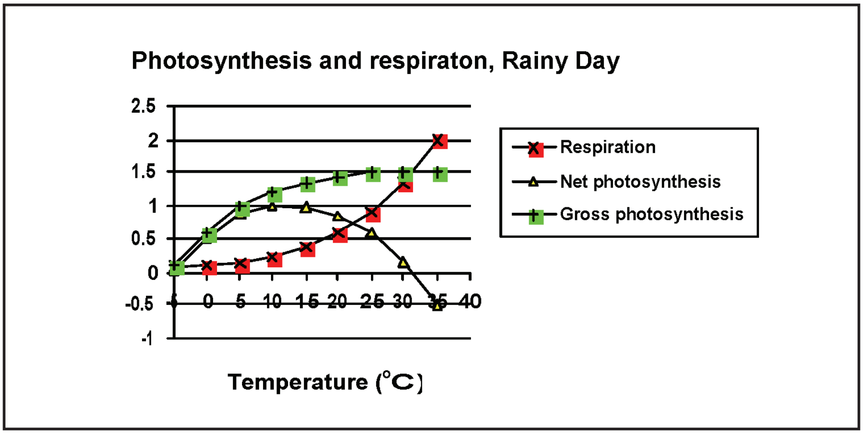

Figure 10. Reduced net photosynthesis on a cloudy day.

- The benefit of light-dependent temperature control is implied.
- The benefit of a positive DIF is implied.

With good solar gain during the day, a positive day/night differential is recommended. The cost/benefit of raising the temperature above ambient outside temperature (at night) and/or above ambient inside temperature maintained by solar gain (during the day) needs to be kept in mind.

To facilitate rapid germination, low to mid 20 °C temperatures are recommended. This allows transfer of the germinant from a "germinating" to a "growing" environment sooner. The germinating environment satisfies the heat sum requirement for seed germination. Respiration of stored seed reserves fuels the process and temperature drives it. A constant day/night temperature is desirable but not necessary. Maximizing heat sum in the most energy efficient manner is the goal. This can be achieved with variable temperatures so heating based on the cost of maintaining a certain delta T is prudent.

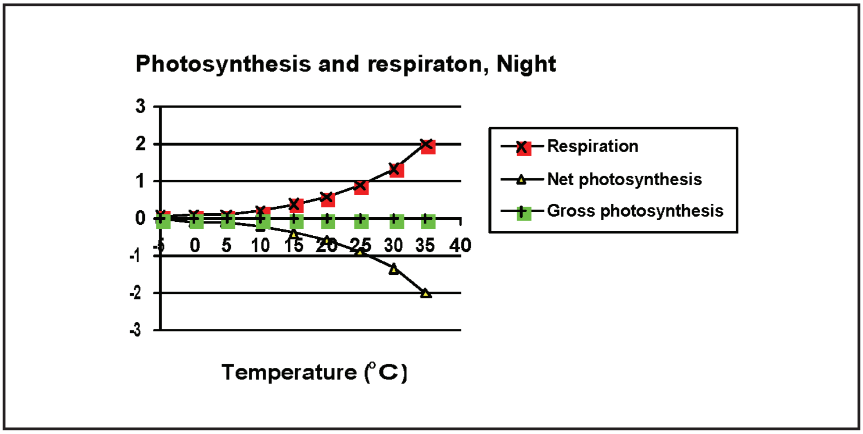

Figure 11. Net photosynthesis is negative at night.

The growing environment needs to balance heat with light to maximize net PS during the day. At night excess heat just increases maintenance requirements within the seedling, which deplete stored energy reserves. To minimize night-time losses, thereby maximizing the 24-h net PS gain, a positive DIF is logical.

SUMMARY

- Raising seed temperature during germination pays.
- Excellent forest seedling crops are being produced using low to mid teens (°C) night temperatures coupled with high teens to low twenties light dependent day temperatures.
- Other plant species grown from seed will respond to above concepts in similar ways, but may have differing optimum temperature regimes.
- Lower temperatures require additional attention to humidity conditions. In particular, one needs to closely monitor dew-point temperature in relation to plant temperature to combat diseases and physiological disorders.

QUESTIONS AND ANSWERS

Sylvia Mosterman: Was the heating system changed from forced-air to radiant heating?

Eric Van Steenis: Yes, infrared radiant heating.

Diego Martinez: Can you explain your use of single and double-poly and what your conclusions were?

Eric Van Steenis: I showed double versus single poly. At -10 °C I have prices per increasing unit of temperature for both types. Single poly just costs more than double poly to bring the greenhouse temperature up from -10 °C. It's cheaper to use double poly since each increment in temperature rise costs you less.