Growing and Energy Conservation

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Abstract: As energy costs increase, resistance is strong to these costs becoming a larger proportion of production cost. Many options can be considered in this battle. This presentation deals only with altering thermostat settings during initial crop growth stages early in the season. Reducing energy requirements in greenhouse crop production while maintaining quality and on-time delivery is a challenge. Two concepts are discussed with respect to greenhouse heating set points: Q_{10} factors during seed germination and DIF during active growth.

Keywords: greenhouse heating, germination, photosynthesis, Q_{10}

Growing and Energy

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

In the nursery, we impose minimum size, time, uniformity, and developmental requirements. Impatience costs money, that is, supplementary energy input in the form of light and heat that is purchased during winter and early spring. 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 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.

Light and heat are the energy forms critical to photosynthesis and "growing." 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. When plants are located outside during the natural growing season, these energy forms are abundantly available and in approximately the correct proportions. In a greenhouse during the winter, however, this is rarely the case. 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 fuels germination. Respiration rate increases with temperature. The goal is fast, uniform, and disease-free germination. Many things can affect germination, but this paper will concentrate on seed temperature. Figure 1 depicts seed response to germination temperature. Given healthy, stratified seeds at appropriate moisture content, a "warm" regime may shorten the germination phase. If approximately 82% germination is the cutoff for switching from a "germination" to "growing" environment, then the "warm" regime allows compression of the germination phase by 5 days (fig. 2).

Does shortening the germination phase pay? Figure 3 depicts the rate, in general, at which energy is supplied to a seedling, and how it accumulates energy over the course of its first growing season. It should be noted that no artificially supplied heat energy results as stored chemical bond energy inside the seedling. The seedling has to capture and store all the energy itself. We cannot "pump it up." The heat energy that we supply helps facilitate the 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.

The large up-front fuel expense is due to the inefficient way heat is supplied to germinating seeds. A handful of seeds are 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 (figs. 4 or 5)?

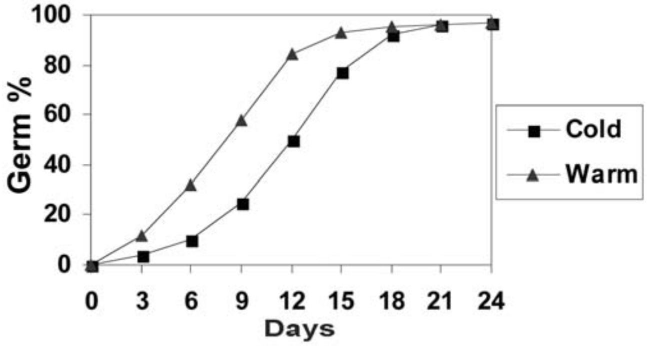

Figure 1. Healthy, stratified seed response to germination temperatures.

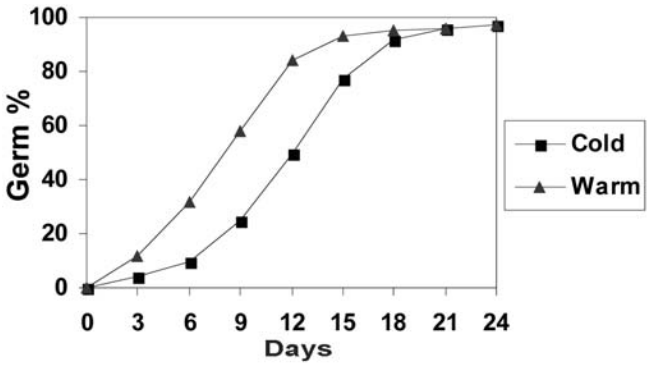

Figure 2. A warmer environment may compress the seed germination phase by 5 days.

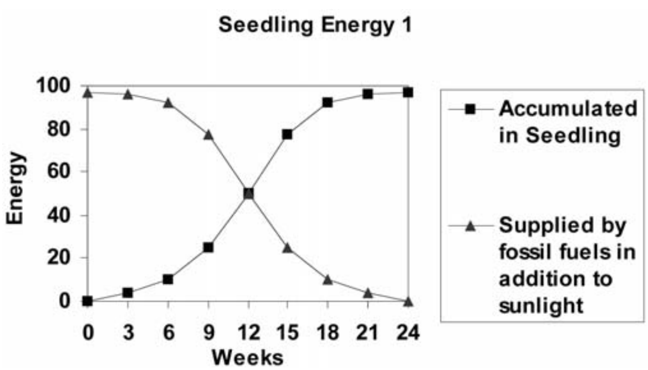

Figure 3. Rate at which energy is artificially supplied to a seedling as compared to accumulated energy in the seedling.

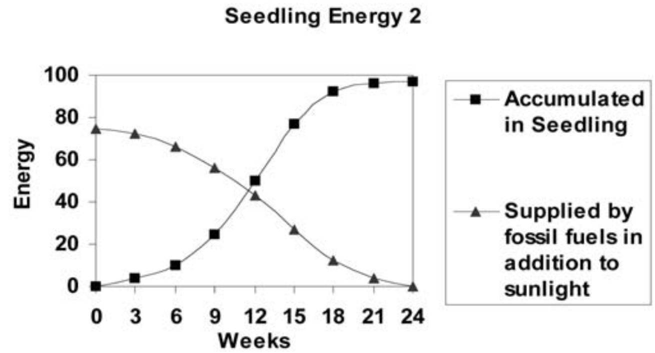

Figure 4. Reduced rate at which energy is artificially supplied to a seedling as compared to accumulated energy in the seedling.

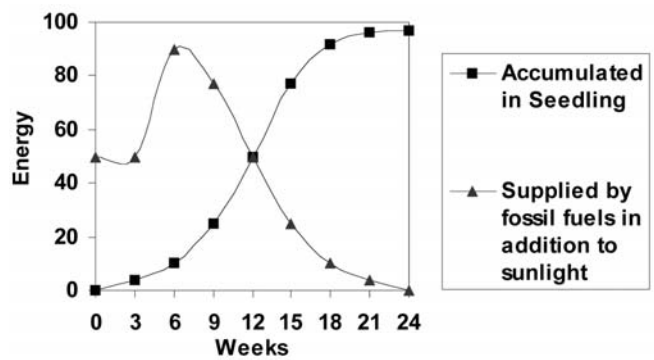

Figure 5. More efficient use of energy in a greenhouse as compared to accumulated energy in the seedling.

Q_{10}

Assume stratification is complete, and moisture, oxygen, and carbohydrate reserves are 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 (18 °F) interval.

Between 5 and 35 °C (41 and 95 °F) for respiration in plants, the Q_{10} factor is approximately 2. This is an exponential relationship. This means that over the specified temperature range, a 10 °C (18 °F) rise results in a doubling of the respiration rate (fig. 6). From the onset of germination until green is showing, respiration rate equals germination rate.

Practically speaking, raising seed temperature from 5 to 15 °C, 10 to 20 °C, or 15 to 25 °C (41 to 59 °F, 50 to 68 °F, or 59 to 77 °F) in each case doubles respiration rate from the lower temperature. Hence, raising the temperature from 5 to 25 °C (41 to 77 °F) quadruples it! Keep this in mind when choosing germination and growing temperature regimes. At a higher initial temperature, where the respiration/germination rate is initially higher, a certain temperature increase results in 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 ≥25 °C (77 °F). But the question remains: does it pay, especially at high per unit energy costs?

The cost of raising the temperature in a growing facility 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. Greenhouse-heating costs increase in a linear, not exponential, fashion (fig. 7).

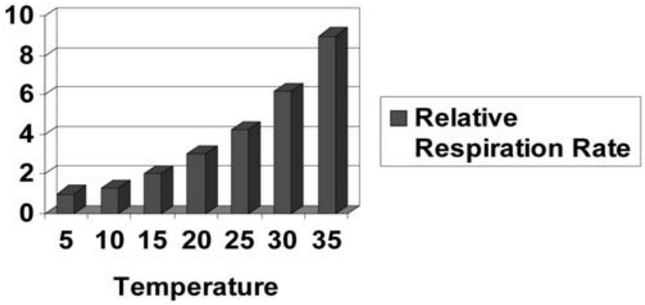

Figure 6. Q_{10} = 2 for plant respiration (5 to 35 °C [41 to 95 °F]).

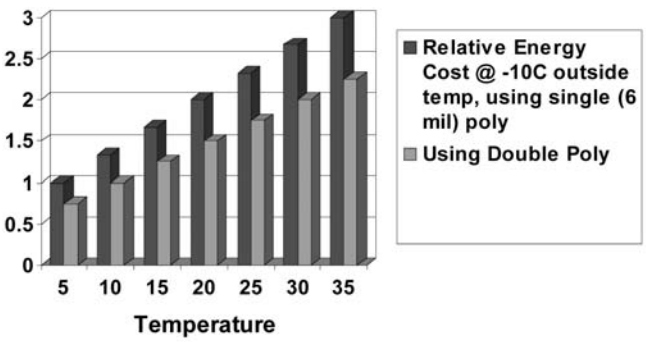

Figure 7. Greenhouse heating is linear.

With each successive increase in greenhouse temperature, the return on the heating investment increases in terms of increased germination speed. In the scenario in figure 8, the first unit of energy is consumed to achieve a greenhouse temperature of 5 °C (41 °F). Respiration (germination) rate is 1. Adding a second unit of energy brings the greenhouse temperature to 20 °C (68 °F) and results in a respiration rate of 3. Adding a third unit of energy brings greenhouse temperature to 35 °C (95 °F) and raises respiration/germination rate to 9 times the rate at 5 °C (41 °F)! In other words, 3 days at 5 °C (41 °F) will give the same germination result as 1 day at 20 °C (68 °F) (that is, seed temperature, not just greenhouse air temperature). Saving 2 days of heating time at 5 °C (41 °F) equals a savings of 33% on the fuel bill to attain the same level of germination.

The bottom line is, 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."

After Germination _______________

Regular growth is an extension of germination. Temperatures that promote growth will promote germination. For many plants, however, optimum germination temperatures are somewhat higher than optimum growing temperatures. This is due to the fact that respiring storage reserves in seeds generate energy requirements for germination type growth, primarily involving reactivation and "unfolding" of previously developed systems and structures. Photosynthesizing organs and "machinery" have maintenance energy requirements that increase exponentially with temperature. This leads to the

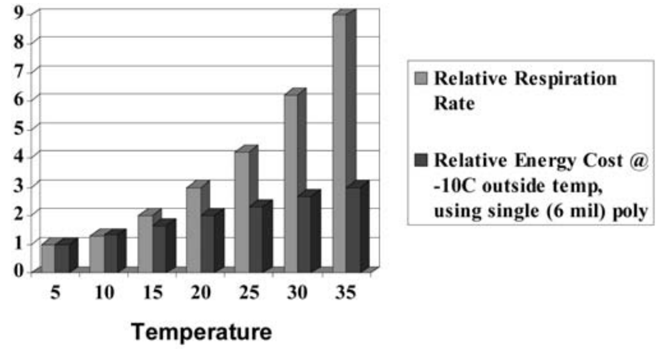

Figure 8. Q_{10} versus greenhouse heating.

concept of "net growth," which equals gross photosynthetic production minus respiratory maintenance requirements.

Net Photosynthesis

Energy conversion is the concept. In a greenhouse during winter/spring, with help from stored prehistoric 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. Photosynthesis and energy storage are a result of several factors:

- Photosynthesis (PS) only occurs in the presence of light (and carbon dioxide);
- Net PS = Gross PS – respiration (RS);
- Net PS is positive if PS > RS;
- Net PS is negative if PS < RS;
- 24-hour **net** PS is positive if daytime **net** PS exceeds nighttime respiration losses;
- Annual **net** PS is positive if growing season **net** PS exceeds non-growing season RS losses;
- Once seed reserves are consumed, young plants start out with virtually no stored energy reserves;
- Respiration of stored carbohydrate reserves (energy) drive "growth";
- Net PS has a lower temperature optimum under low light (figs. 9 and 10; note the shape of each line);
- Dark period temperature must 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 seedlings 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); and
- A poor net PS day can be bright and very hot, bright and very cold, dull and warm, and so on.

For all aspects of the preceeding discussion, the benefit of **light dependent** temperature control and a **positive** differential between day/night temperatures (DIF) are implied.

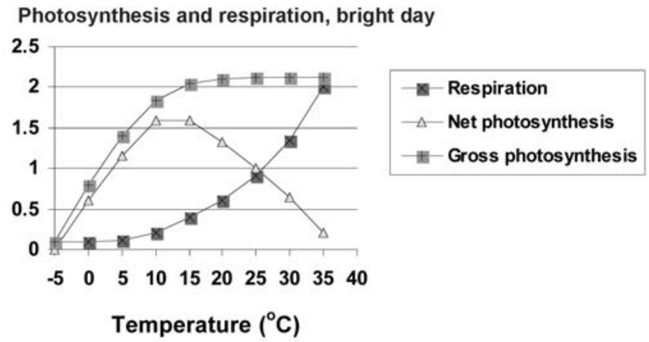

Figure 9. Photosynthesis and respiration on a bright day.

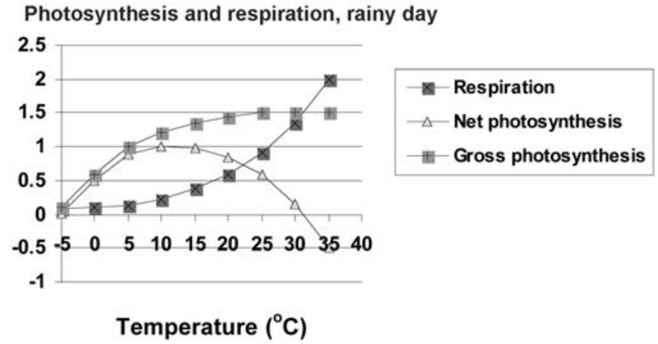

Figure 10. Photosynthesis and respiration on a rainy day.

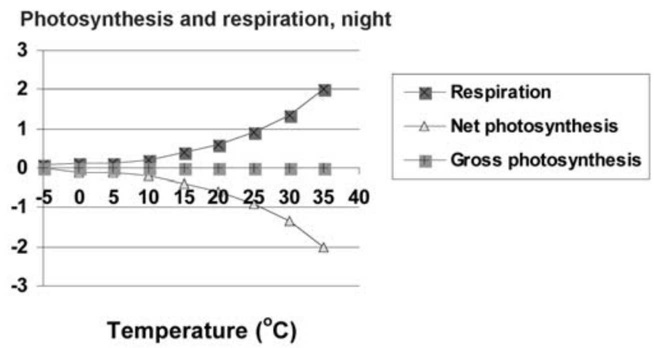

Figure 11. Photosynthesis and respiration at night.

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**, temperatures from 20 to 25 °C (68 to 77 °F) 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. Therefore, heating based on the cost of maintaining a certain temperature change (ΔT) is prudent.

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

Summary

- Raising seed temperature during germination pays.
- Excellent forest seedling crops are being produced using night temperatures between 10 to 15 °C (50 to 59 °F) coupled with **light dependent** day temperatures between 15 to <25 °C (59 to <77 °F).
- 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.

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.