THE GREENHOUSE ENVIRONMENT: HEAT AND LIGHT

Jonathan M. Frantz USDA-ARS, 2801 W Bancroft, Mail Stop 604, Toledo, OH 43606
jonathan.frantz@utoledo.edu

To maximize productivity, the genetics of a plant must "match" an optimized environment, much like getting the most out of an automobile relies on the car's make and model and fuel, upkeep, roads, and road conditions.

UNITS

There are, unfortunately, a lot of units of measurement for the environment such as light and temperature. The most common temperature units are Fahrenheit (°F) and Celsius (°C). To convert °C to °F, use the following equation: (9/5 × °C) + 32
And to convert °F to °C, use the following equation: 5/9 × (°F – 32)
For light and radiation, there are many more units. I use the units of micromoles (µmol) and most often express it in terms of µmol per area per time (µmol m^{-2} s^{-1}) or, over the whole day, mol m^{-2} d^{-1}. The reason for the use of these units is that it directly corresponds to photosynthetic potential, the driver of crop growth. The equivalent unit is the Einstein or micro-Einstein. Many growers use footcandles, though the number of growers using these units is steadily decreasing. The conversion between footcandles and micromoles is roughly 5× micromoles = footcandles. The exact conversion depends on light type and time of day, whereas micromole has no such dependency. Still others use W m^{-2}. This is a good unit to use to predict water use for crops, but for conversion to micromoles and utility to predict photosynthesis depends on time of day and type of lamp. For this paper, I will use the units of µmol m^{-2} s^{-1} for light and °C for temperature.

HOW MUCH LIGHT?

Light quantity is often limiting in a greenhouse setting and can easily be ½ that found in the field. It is expensive, however, to add electric lamps in sufficient quantities to boost productivity during the day and so electric lamps are primarily used to extend the day in greenhouse production. How much light should you have? Many experiments have shown lettuce yield, for example, to plateau around 400 Φmol m^{-2} s^{-1}, but we have found yield for lettuce and most crops can increase up to and probably beyond 1000 Φmol m^{-2} s^{-1} if other environmental parameters are optimised as well. This does not mean that growers should spend a fortune on electric lamps to squeeze a few extra micromoles of light in their greenhouses. However, growers should not try to avoid high light in the day out of fear of saturating photosynthesis or photobleaching leaves, provided other environmental and management issues are optimised.

An interesting point about light is the issue of light quality, especially when selecting electric lamps. Research done at Utah State University indicates that high pressure sodium (HPS) lamps may stimulate leaf expansion due to their lack of blue light. This means that HPS instead of metal halide (MH) lamps may enhance productivity through their stimulation of leaf expansion caused by blue light deficiency. This work was done in controlled environments so the light environment was determined solely by the selection of lamp type. It is not known if this stimulation would occur in a sunlit greenhouse environment already containing ample blue light with HPS lamps used only as a supplement.

MEASURING LIGHT

Our eyes are poor at detecting light quantities. Fortunately, there are several, good, inexpensive light or quantum meters available on the market today. They may be sold under the names of Light Meter, Quantum Meter, Flux Meter, PPF Sensor, PAR sensor, PAR meter, etc. When purchasing one, make sure the measures the energy from roughly 400 nm to 700 nm, since this is the visible light and is the most important for driving photosynthesis. These meters can be purchased with switches to convert between different units, attached to meters that can be remoted from the measuring location, containing single or multiple light sensors, or calibrated for your type of light (electric or sunlight). Check with the distributor or manufacturer for your needs.

I would encourage you to measure early and often, in as many places as you can to get a feel for the amount of light your crop receives. Remember, you are measuring light not where you are standing, but where the sensor is located. Therefore, if you want to know how much light is striking the surface of your crops, measure light at the surface of your crops. If you are interested in getting an idea of light distribution of your greenhouse or under electric lamps, record the light in a grid pattern in the area in which you are interested. Once you get a sense of how light distribution patterns change in time and in space, you can begin to make fewer measurements and understand how those fewer measurements correlate to the rest of your growing area.

TEMPERATURE

It has been well established that the single biggest driver for yield improvement per area is increased light interception. Therefore, any opportunity to increase light capture per area should be investigated, including elevated light and denser spacing.

Leaf emergence and leaf expansion rates are greatly influenced by temperature so increasing temperature is an indirect way to improve light capture. Photosynthesis, and thus yield, is strongly correlated to ground cover and light capture (Figure 1) regardless of temperature. As an added benefit, some species

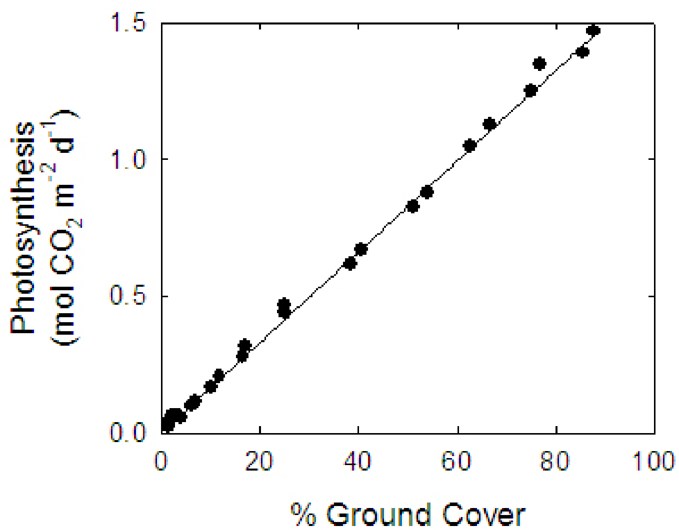

Figure 1. Photosynthesis and yield increase in direct proportion to the amount of light a crop absorbs.

and cultivars have more chlorophyll or stronger variegation in elevated temperatures, which could improving the appearance or quality of your crops.

Photosynthesis is greatly influenced by temperatures. Under "normal" air or CO_2 conditions (about 400 ppm or µmoles CO_2 per mole of air), photosynthesis generally decreases as temperatures rise. This is largely due to a process called photorespiration, but it is a process that can be greatly minimized under elevated CO_2. Between normal CO_2 concentration and 1000 ppm, productivity increases linearly with CO_2 addition. CO_2 can be prohibitively expensive, but doesn't need to be. If CO_2 is added from waste combustion products, be aware of ethylene contamination, a product of incomplete combustion that is also a plant hormone that can lead to defoliation, sterility, and foliar damage. CO_2 can be limiting often in tightly sealed greenhouses during the day.

MEASURING TEMPERAURE

Do not assume that your thermostat is an adequate representation of your air temperature in the entire greenhouse. In fact, some thermostats may be as much as 12 °F off calibration out of the box (John Bartok Jr, 2005, personal communication). Remember, you are measuring the temperature at that point and the actual temperature of the air may vary across the growth space, much as light varies in your greenhouse. We are all familiar with mercury thermometers, but many of us may be hesitant to use them in a greenhouse for fear of breakage. There are many types of thermocouples (wire designed to measure temperature) and thermistors (temperature sensitive resistor) available at about the same cost as a light meter. See the MEASURING LIGHT section to see where and how often to measure air temperature.

Some growers have either switched completely or supplement their air temperature measurements with measuring leaf or crop canopy temperature. This is done by using an infrared (IR) transducer, sold at many distributors under different names, pointed at the surface of interest. This can prove more helpful than measuring air temperature, but there are few things to consider when measuring temperature in this manner. The distance from the sensor to the target greatly influences the measured area. The farther away from an object, the larger the circle of measured area will be. Find out, if possible, your field of view or distance:area ratios, because this will determine how large of an area you are measuring at any given distance. There is not a clear cut off of target temperature to “noise” or surrounding area. The larger the field of view, the closer you must be to your target to ensure of measuring the target temperature. However, large fields of view can be useful when measuring large plants or closely spaced plants because the there will be less spot variation.

AT WHAT COST?

Ultimately, the determinant of yield may be what you can afford to grow. The optimum environmental settings will not match the optimum economic cost setting. The actual setting should be somewhere in the middle. There is some evidence that many plants average temperature over 24 hours, so there may be leeway in reducing night temperature more if the day temperature, when you can get free solar heat, is higher than “normal”. With the cost of heating greenhouse structures spiralling, there will be a temptation to lower the temperature set point. Prior to doing that, ensure your greenhouse is well insulated and conserving as much heat as possible. Can you remote your electric lamp ballasts to under the bench? Can you heat the nutrient solution or root zone and lower your air temperature? What impact will lowering temperature have on productivity, quality, and timing? Can you warm plant surfaces, using an IR heat source, more efficiently now and lower air temperature?

CONCLUSION

Growers must walk a fine line between rapid growth and reduced quality or higher energy costs. With changes in temperature, light, and CO_2, productivity can be more than doubled for some crops.

Is it worth it? The larger the plant, the less room there is for error in managing quality. Managing the environment while simultaneously optimizing plant nutrition provides the key to achieving high quality crops. The faster the growth rate, the greater likelihood of encountering nutrient deficiencies such as Ca, Fe, and B. If you plan on altering the light and temperature environment, first measure your environment, ensure your thermostats are calibrated, and conserve what you already have before adding new systems.

DISCLAIMER

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products or vendors that also may be suitable.