Grower 101:

SUPPLEMENTAL LIGHTING

Important information you need to incorporate supplemental lighting.

By A.J. Both

Supplemental lighting is used in greenhouses to increase crop production during time periods with low levels of solar radiation. These time periods usually occur during the winter months, but cloudy summer days can be as dark as some of the darker winter days. Thus, if crop production is on a tight schedule, supplemental lighting may be required year-round. Sometimes, photoperiod lighting is also defined as supplemental lighting. But since the light intensities required are very low, and photoperiod lighting consumes limited amounts of energy, it is not considered in the context of this discussion. Despite the installation and operating costs associated with supplemental lighting systems, growers are discovering the benefits. These systems can help improve crop quality, keep production on schedule and reduce the length of the growing cycle. Thus, growers produce a higher-quality product while keeping their production schedules on target, and they are able to produce more crops per year.

LIGHT UNITS

The preferred unit for measuring light for plant production is μmol m^{-2} s^{-1} (pronounced: "micromol per meter squared per second"). This unit expresses the amount of particles (photons or quanta) of light incident on a unit area (m^2) per unit time (second). The portion of the light spectrum the plants use for photosynthesis is called Photosynthetically Active Radiation (PAR, 400-700 nm, nm = nanometer), and it is expressed in the unit of μmol m^{-2} s^{-1}. Sensors used to measure PAR are called quantum sensors and have carefully designed filters such that no light outside the PAR waveband is measured. Our human eye is able to detect light in a slightly larger waveband of approximately 380-770 nm. To measure light in this waveband, a foot-candle meter (or a lux meter) can be used. But measurements with a foot-candle meter include some light with wavelengths outside the waveband used by plants for photosynthesis. Therefore, using a foot-candle meter introduces a small error when we are only interested in measuring the amount of light available to plants for the process of photosynthesis. For this reason, the use of a foot-candle meter is not recommended when evaluating the light environment for plant production. It is possible to convert a measurement taken with a foot-candle meter into a μmol m^{-2} s^{-1} value, but the correct conversion factor depends on the light source and is, in the case of mixed light sources, not always easily determined.

MH OR HPS

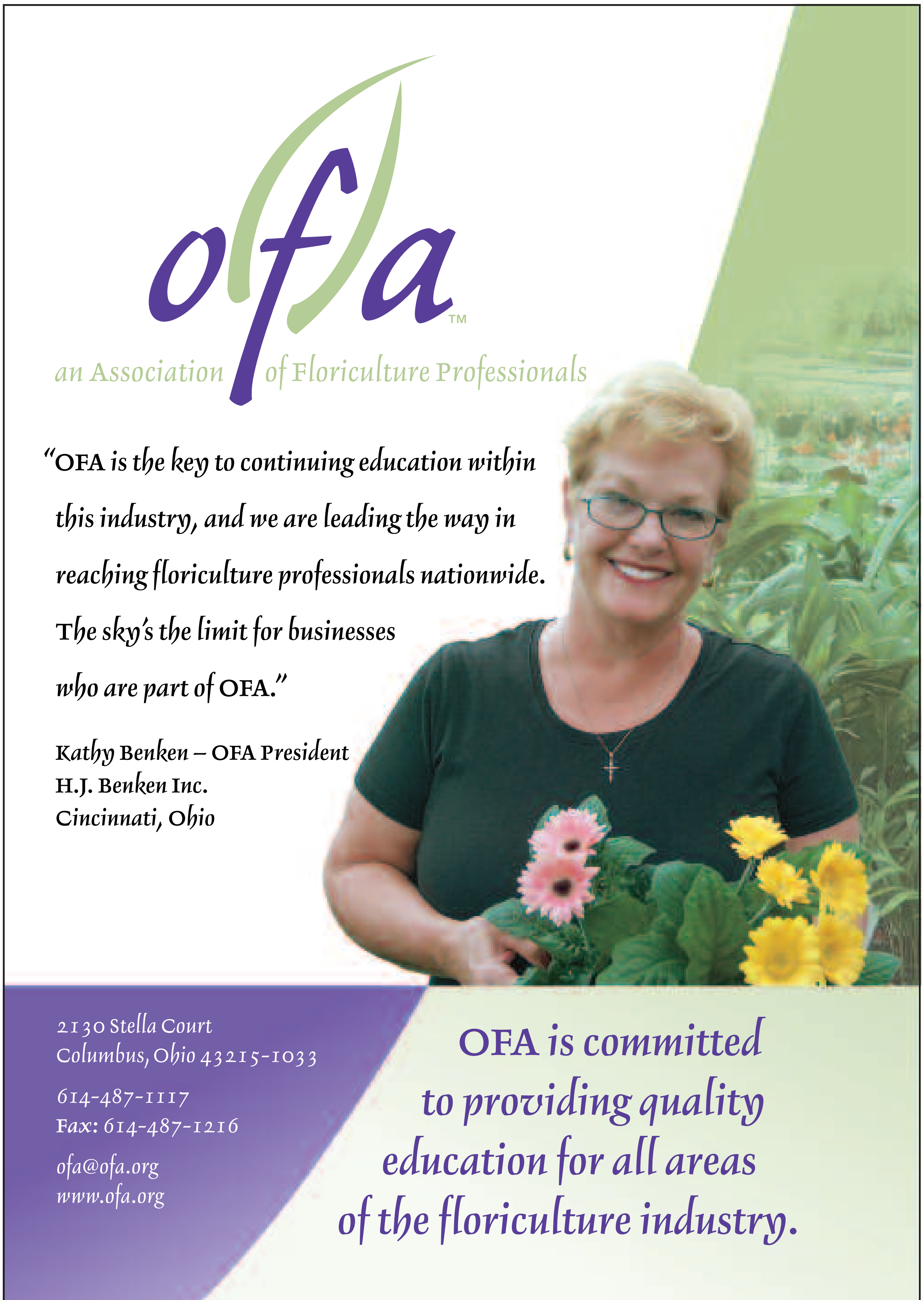
The most efficient lamps used for supplemental lighting in greenhouses are the so-called high intensity discharge (HID) lamps. Two such lamps are the metal halide (MH) and the high-pressure sodium (HPS) lamps. MH lamps produce a more white-colored light, while HPS lamp light is more yellowish orange (similar to street lamp light). HPS lamps are slightly more efficient in converting electric energy into PAR light and have an average rated lamp life up to three times longer than MH lamps. MH lamps produce a little more blue light that is important for the proper development of some crop species. Because of their higher efficiency and rated lamp life, HPS lamps are most often used for supplemental lighting in greenhouse operations. Common lamp wattages are 400, 600 and 1,000.

INSTALLATION CONSIDERATIONS

When installing supplemental lighting systems in greenhouses, several factors should be considered. First, the average amount of solar radiation for the location should be investigated.

This will give an idea of the range of solar radiation conditions at the site. One way to determine the amount of light available for crop production at a particular location in the United States is to consult the database of solar radiation data maintained by the National Renewable Energy Laboratory in Golden, Colo. (www.nrel.gov). This database contains solar radiation data for 239 locations across the United States and its territories. For plant production purposes, the solar radiation data can be converted into the units of mol m^{-2} d^{-1}, indicating the daily sum (integral) of light available for photosynthesis (1 kWh m^{-2} d^{-1} = 7.49 mol m^{-2} d^{-1}). Second, the type of greenhouse structure, glazing and equipment installed will have an impact on the transmission of sunlight. Third, the type of crop (or crops) grown in the greenhouse will determine the plant's requirements (such as light intensity, duration or light integral). Fourth, the available space in the greenhouse to hang lamps will have an impact on the uniformity of supplemental lighting (the less space available for taller crops in lower greenhouses, the less uniform the light distribution). Finally, the plant's requirements should be compared to the available amounts of sunlight to calculate the necessary amounts of supplemental lighting.

It is usually not economical to install lighting systems that provide high light intensities in greenhouses because of the large number of lamps required. Therefore, supplemental lighting systems can be designed to provide a certain light integral during a 24-hour period such that the sum of the supplemental light integral and the solar radiation integral meet the plant's requirements for even the darkest day of the year. The light integral supplied by the supplemental lighting system depends on the average light intensity provided by the lamps and the duration of operation. The light intensity supplied by commercial supplemental lighting systems usually is not higher than 200 μmol m^{-2} s^{-1} (0.72 mol m^{-2} hr^{-1} or 17.3 mol m^{-2} per 24-hour period).



LIGHT UNIFORMITY

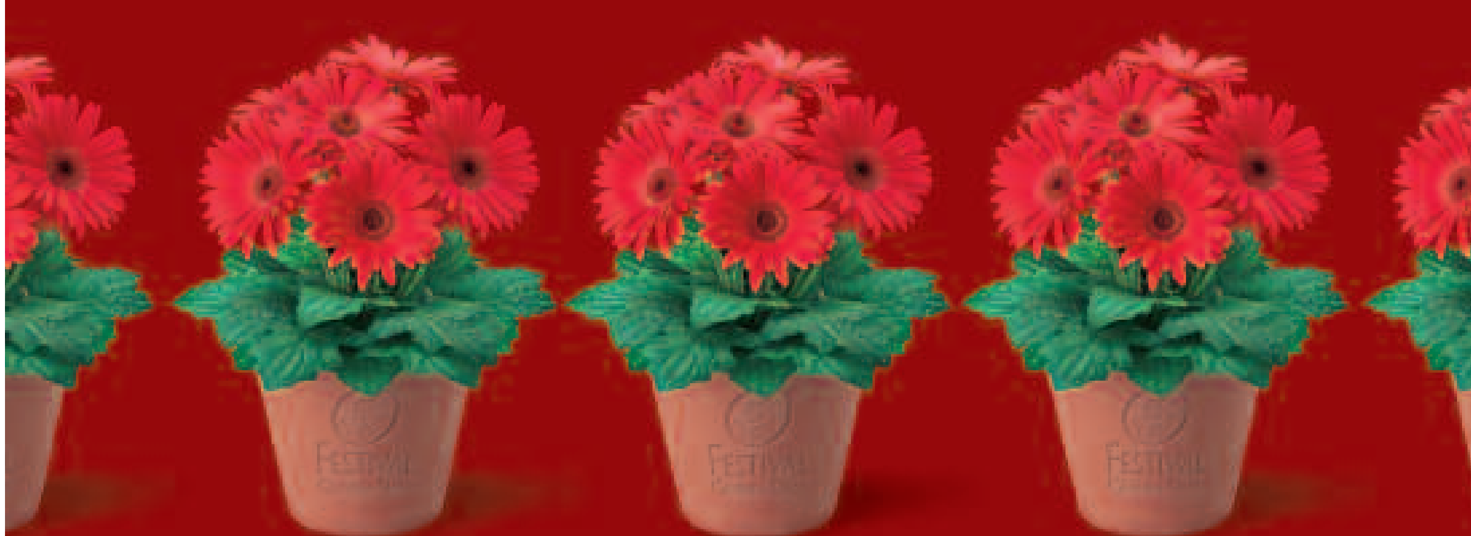
In addition to light intensity, light uniformity is an important factor to consider when designing lighting systems for greenhouses. In general, except when clouds are passing overhead or when structural elements create shading patterns, sunlight is uniform from one location to the next inside a greenhouse. However, due to the distance between lamps and the distance between the lamps and the crop, supplemental lighting systems will always provide non-uniform lighting patterns over a plant canopy. It is the task of the designer to optimize light uniformity by carefully calculating the light distribution from each lamp and the different paths the light can travel from each lamp to the crop underneath. Fortunately, computer software programs exist to assist the designer with this complicated task and in general, a careful design results in very acceptable light distribution and uniformity over a crop canopy.

REFLECTORS

Most supplemental lighting units are outfitted with a reflector that directs the light generated by the bulb downward onto the crop. Different manufacturers use different materials and designs. The trick is to design a reflector that directs the light away from the bulb and spreads it uniformly over the crop. Reflectors should not be too big because they may block significant amounts of solar radiation from reaching the crop. Installed in greenhouses, reflectors tend to get dirty over time and need to be cleaned periodically for optimum reflectivity.

OFF-PEAK OPERATION

To make the operation of a supplemental lighting system as economical as possible, these systems are sometimes operated exclusively during periods of the day with off-peak electricity rates (e.g. from 10 p.m. to 6 a.m.). However, during the darker months, this could result in two light periods for a crop during every 24-hour period (one starting at sunrise, ending at sunset and followed by a (short) dark period; the other continuing with the supplemental lighting period and followed by a brief ➧



dark period before sunrise). Not every crop might thrive under these conditions. Some crops require an extended dark period (e.g. tomatoes), resulting in the use of supplemental lighting during hours of the day with more expensive electricity rates. Careful (computer) control of the operation of lighting systems will help reduce operating costs.

DAILY LIGHT INTEGRAL

For some crops, and especially for the vegetative growth phase, a (linear) relationship exists between total amount of light received and plant growth. This relationship brought forth the idea of providing plants with the same light integral (or light sum) every day of the year and independent of the amount of solar radiation received. Whenever the amount of light provided by sunlight would be less than the target light integral, the remainder would be added with a supplemental lighting system. Whenever a crop would be in danger of receiving more than the target light integral, a shade curtain would be deployed. Controlling such a lighting system with the goal of providing the exact same light integral every day of the year is only feasible with the help of computer software. Such software has been developed, and it enables the computer to keep track of the amount of light received since sunrise. By comparing the amount of light received with a calculated prediction of the total amount of sunlight received at sunset and knowing the desired daily light integral, the computer determines when to operate the lighting or shading system. In addition to making sure the plants receive the same light integral every day, the control system can also make maximum use of the hours of the day with off-peak electricity rates to operate the supplemental lighting system.

CARBON DIOXIDE

For photosynthesis, plants need both light (PAR) and carbon dioxide. Both need to be available in sufficient quantities for neither one to become the limiting factor (e.g. if there is enough light but not enough carbon dioxide, carbon dioxide becomes the limiting factor and vice versa). Therefore, when using supplemental lighting to increase plant production, it is important to maintain sufficiently high carbon dioxide concentrations inside the greenhouse. Especially during the colder months of the year, when (very) low ventilation rates are needed to maintain the desired greenhouse temperature, the carbon dioxide concentration inside the greenhouse can drop significantly because little or no fresh air (with more carbon dioxide) enters the greenhouse. Under these low-ventilation conditions, it may be economically feasible to boost the carbon dioxide concentration inside the greenhouse to levels as high as three times the ambient concentration, resulting in increased photosynthesis and thus plant growth.

Research indicates that within certain limits, it is possible to reduce the required daily light integral, while at the same time, increasing the carbon dioxide concentration for the same overall plant production. This points to possible significant savings because adding carbon dioxide to the greenhouse environment is cheaper than adding supplemental light. Computer control software is needed to assist the grower with the decision of when to add carbon dioxide to the greenhouse, what target concentration should be used and when to operate the supplemental lighting system. During the warmer months of the year, when significant ventilation is required to maintain the target greenhouse temperature, carbon dioxide enrichment is not cost effective because the released carbon dioxide would be immediately exhausted from the greenhouse.

LAMP REPLACEMENT

Maintenance of supplemental lighting systems is important and should not be overlooked. Just like any other piece of equipment, failures do occur and need to be corrected as soon as possible. Lamp failures create non-uniform light distribution patterns, which can quickly lead to non-uniform plant production. In addition to incidental failures, the light output of lamps slowly degrades over time. The rate of degradation depends on the type of lamp used and the operating conditions (e.g. temperature). By knowing the approximate rate of degradation (check with the manufacturer), a lamp replacement schedule can be developed such that the overall light intensity does not drop below a certain minimum acceptance level. Instead of replacing all lamps at once, which can be expensive, lamps can be replaced in groups such as one greenhouse bay at a time or better yet, every other lamp or every other third lamp, etc. GPN

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