# PUTTING LIGHT INTENSITY INTO PERSPECTIVE

A practical guide to managing sunlight, shade and supplemental lighting

BY ERIK RUNKLE

In the last two decades, most horticultural operations have transitioned from footcandles and lux to micromoles as the unit of measurement for light intensity.

The use of micromoles is a simplification of the photosynthetic photon flux density (PPFD), which is the number of photons within the 400 to 700 nm waveband delivered per square meter and second, or $\mu mol \cdot m^{-2} \cdot s^{-1}$.

This value is instantaneously measured by a quantum sensor, which is sometimes called a PAR (photosynthetically active radiation) sensor. PAR refers to the waveband of light primarily used by plants for photosynthesis.

Measurements in footcandle and lux units are based on the human eye's sensitivity to light. While there are similarities between peoples' and plants' perception of light, there are also important differences. Most notably, our perception of red and blue light is relatively low compared with green light.

In contrast, the utility of light for photosynthesis is similar for blue, green, and red photons; there is no significant bias. This key difference is especially important for light emitted by light-emitting diode (LED) fixtures.

We can (and should) manage greenhouses, and the crops grown inside, based partly on sunlight conditions. Management decisions can be aided by putting light intensities into perspective.

Transmission of sunlight into a greenhouse considerably varies, depending in part on parameters independent of the greenhouse (latitude, time of year, elevation, seasonal weather patterns, etc.) and parameters dependent on the greenhouse (glazing materials, shading materials, and overhead obstructions such as hanging baskets or lighting fixtures).

In addition to greenhouse-specific transmission of sunlight, crops vary in their response to light intensity as well as other environmental parameters that interact with it, such as temperature and carbon dioxide ($CO_2$) concentration.

## GREENHOUSE TRANSMISSION OF SUNLIGHT

The maximum intensity of sunlight outside of a greenhouse is roughly 2,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at solar noon on a clear, summer day (**Fig. 1**). The value can be lower or slightly higher, depending on altitude, humidity and air pollution.

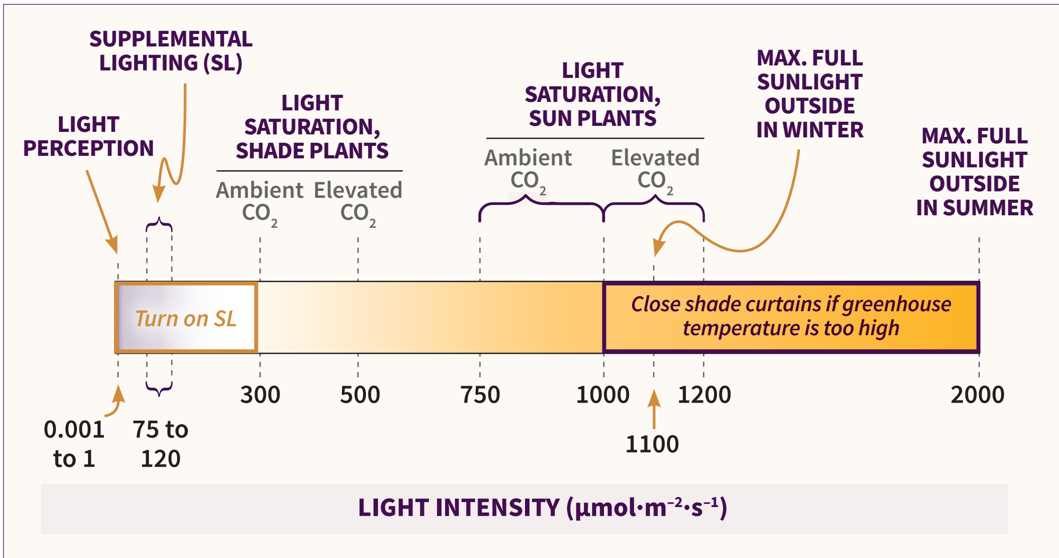


Fig. 1. Light intensity values for light perception, sunlight outdoors, supplemental lighting (SL), light saturation for photosynthesis, and operating SL and shade curtains inside greenhouses. Values are representative of ornamental plant production. Management decisions should also consider other environmental factors and varying responses among crops.

In the winter, the maximum value decreases by as little as 30% (southern U.S.) to as much as 60% (northern U.S.). While an average maximum winter light intensity is around 1,100 $\mu mol \cdot m^{-2} \cdot s^{-1}$, it could vary from 800 to 1,400 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Inside a greenhouse that maximizes solar transmission (e.g., clean glass glazing, minimal structure, no shading compounds or curtains), about 75% of sunlight reaches plants. In contrast, a triple-layer polyethylene greenhouse may only transmit 50% of sunlight, and even less if there are overhead obstructions or the poly is old.

Therefore, maximum sunlight levels inside a greenhouse could be as high as 1,400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on a clear summer day to as low as 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in the northern U.S. in the winter. Most of the time, light intensities are lower because of clouds, the sun is at a lower angle, or both.

## LIGHT INTENSITY AND PLANT GROWTH

Photosynthesis and plant growth rate typically increase as light intensity increases, until the plant's saturating value. The saturating light intensity depends on the crop, $CO_2$ concentration and temperature.

A saturating light intensity for shade crops, such as begonias, ferns and seed impatiens, is approximately 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at ambient $CO_2$. If $CO_2$ is enriched to 800 to 1,000 ppm, photosynthesis and growth of many shade crops increase with light intensity until around 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$. While some shade crops tolerate light intensities higher than saturation values, others can develop leaf scorch or bleaching.

Most floriculture and vegetable crops grown in commercial greenhouses are sun crops with a saturating light intensity at ambient $CO_2$ of around 750 to 1,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$. With supplemental $CO_2$, light saturation increases by about 20%, to 1,000 to 1,200 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Assuming 65% solar transmission for a commercial greenhouse in the northern U.S. and no use of shading materials, saturating intensities of sunlight for sun crops rarely occur from November through February, but occur an average of 1-2 hours per day in March and October, 3-4 hours in April and September, and 6-8 hours from May to August.

In much of the southern U.S., growers receive 1-2 hours more per day of saturating sunlight in the spring and fall, and 1-2 hours less per day in the summer. This provides perspective for the use of supplemental lighting and shading to manage the greenhouse light environment.

## LIGHT INTENSITY AND SUPPLEMENTAL LIGHTING

The intensity of supplemental lighting installed by commercial growers has been creeping up. This is partly because growers have increasingly realized the benefits of supplemental lighting, especially in propagation during the winter. With conventional lighting from high-pressure sodium fixtures, a typical supplemental lighting intensity for ornamental crops was 60-75 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

With more energy-efficient LEDs, more recent supplemental lighting installations are at 75-120 $\mu mol \cdot m^{-2} \cdot s^{-1}$. While this intensity is low compared with saturating light intensities for sun crops, it meaningfully increases the daily light integral (DLI) when delivered for up to 16-20 hours per day. Note that supplemental lighting intensities are usually higher for some fruiting crops (such as tomato) and cannabis.

Ideally, supplemental lighting should operate based on time, the intensity of sunlight, and when possible, the DLI accumulated that day and/or the average DLI received the prior 3-4 days. This necessitates controlling the lighting with an environmental control computer. When only timers are used, the lights stay on even during sunny conditions, when the additional light is less useful.

The threshold for turning on supplemental lighting is somewhat situational, depending on the crop, target DLI, and DLI already or recently received. A typical setpoint for lights to turn on above ornamental sun crops is when sunlight is less than 150-200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ inside the greenhouse or 200-350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ outside the greenhouse. Setpoints could be lowered when the recent average DLI is below the target, and vice versa. Once the average DLI from the sun is above the target (often 10-12 $mol \cdot m^{-2} \cdot d^{-1}$), fixtures can be turned off.

## LIGHT INTENSITY AND SHADING

Shade curtains and whitewash are primarily used to mitigate the temperature rise inside a greenhouse and to decrease plant temperature stress. In doing so, light intensity is often decreased by 40-60%. Thus, fewer hours of saturating sunlight are received once temperatures become warm, and in some cases, none during the summer.

Considering the trade-off that exists between temperature management and light intensity, shading decisions should be based on both. Program shade curtains to deploy based on the intensity of sunlight and the greenhouse temperature.

For example, deploy shade curtains if sunlight outdoors exceeds 1,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and (not or) the greenhouse temperature is 4-6° F above the desired setpoint. If only one condition is met, keep the curtains open to maximize plant growth.

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