

Modifying sunlight in greenhouse crop production

Sunlight is the major light source for photosynthesis and plant growth as well as the major energy source for heating greenhouses. Growers are increasingly modifying sunlight by enriching it with supplemental lighting, decreasing it by applying shading compounds or deploying retractable shade/energy screens, and shortening or lengthening its daily duration to regulate flowering of photoperiodic crops (**Figure 1**). Some are also modifying the solar spectrum, particularly when sunlight is abundant or excessive.

Let's start by describing the solar spectrum. On an energy basis, approximately 43% of sunlight is in the photosynthetically active radiation (PAR) waveband, which is 400 to 700 nm. About 6% is as ultraviolet (UV) and 51% is as infrared (IR) radiation. Most of the IR from the sun is near-infrared radiation (NIR) (700 to 2,500 nm). IR increases plant and greenhouse temperature. We usually measure IR radiation with a pyranometer, which is expressed in watts per square meter ($W \cdot m^{-2}$).



Figure 1. Although we rely on sunlight to produce crops inside greenhouses, growers modify it to create more favorable growing conditions.

On a photon basis, which is more relevant for photosynthesis and plant growth, approximately 48% of sunlight is in the PAR waveband. Specifically, the sun emits around 12% blue light, 17% green light and 19% red light. In addition, a little more than 9% of the photons emitted by the sun are as far-red light, which increases plant elongation and overall growth.

About 3% of the photons are as UV radiation, although most glazing materials block much of this. PAR is usually measured by a quantum sensor and has the unit of micromoles of photons per square meter and second ($\mu mol \cdot m^{-2} \cdot s^{-1}$). Alternatively, sensors can measure extended PAR (ePAR; 400 to 750 nm) to account for the full spectrum that drives photosynthesis.

REFLECTIVE SHADING

From late spring to early autumn, sunlight can be excessively high. Whitewash and white or aluminized screens reflect sunlight, which decreases PAR and the rise in plant and greenhouse temperature. In many cases, the decrease in PAR is acceptable, but it can decrease yield in some high-light crops such as tomatoes.

In addition, many shading products and glazing films diffuse incoming sunlight. Diffuse light penetrates deeper into a crop canopy, which can increase overall plant photosynthesis and decrease spikes in leaf temperature.

NIR-SELECTIVE SHADING

Selective shading compounds have been engineered to transmit relatively more PAR than NIR. In other words, more photons of PAR are transmitted per watt of energy. These are more expensive than non-selective shading compounds, but they can be cost-effective, especially in warm and hot climates. These shading materials are available as liquids applied to the glazing, where use is seasonal, or as films for year-round use. The "cooling films" are most appropriate for high-sunlight regions such as the southwestern U.S.

In one study we performed at Michigan State University, a selective shading paint externally applied to the greenhouse glazing during the summer increased the number of PAR photons per unit of energy from sunlight by 44%, from 1.8 to 2.6 $\mu mol \cdot J^{-1}$. The air and plant temperatures inside the small greenhouse sections with the NIR-selective shading compound were also slightly lower. The magnitude of the effect of the NIR-selective shading will be greatest in large greenhouses and those with relatively poor ventilation.

FLUORESCENT/LUMINESCENT FILMS

These materials absorb high-energy wavebands (often UV and/or blue light) and re-emit them as longer wavelengths. The result is a decrease in PAR but an altered sunlight spectrum, often delivering less blue and more red light. This shift in spectrum can increase extension growth, which in turn can sometimes increase growth and yield. The potential of these films is greatest in regions with high sunlight levels during most or all of the year. Challenges with these materials include their longevity and cost effectiveness.

THERMAL IR FILMS

Also called heat-retention films, these contain materials that block outgoing longwave IR radiation. They are commonly used as the inside layer of double-polyethylene greenhouses to reduce heat loss at night. In cold climates, their return on investment is usually less than one year.

LIGHT-EMITTING DIODES (LEDS)

Supplemental LED lighting can modify the solar spectrum, especially when delivered on cloudy days and at night. The potential to elicit specific growth responses, such as more compact growth, is greatest when the average daily light integral (DLI) from the sun is low (e.g., less than 6 $mol \cdot m^{-2} \cdot d^{-1}$) and when the supplemental DLI is moderate to high (e.g., at least 3 $mol \cdot m^{-2} \cdot d^{-1}$). Since sunlight emits a moderately high percentage of far-red light, supplemental lighting with a high percentage of red light and moderate percentage of blue light can suppress unwanted elongation. gpn

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