UTILIZING SUPPLEMENTAL LIGHTING IN *URBAN CROP PRODUCTION ENVIRONMENTS*

Electric lighting is needed to either supplement naturally available sunlight, extend day length or serve as the sole source of light.

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A renewed interest in urban and controlled environment agriculture (CEA) has come with the increased interest in locally and sustainably produced food. Consumers are more and more demanding that their produce be chemical-free, and they want to know where and how it was grown. Clearly, producing crops in urban environments has key benefits such as proximity to market, increased shelf life, and consumer knowledge about production practices. However, there are also major challenges such as the availability of suitable land that is free of hazardous materials, high property values and taxes, permits and regulations, finding skilled labor, and competition from cheaper field-grown products. The advantage of CEA is that most environmental conditions can be carefully controlled, which allows for year-round production and all but guarantees the highest potential yields. Typical growing structures range from high tunnels to greenhouses (**Fig. 1**), as well as re-purposed buildings (**Fig. 2**) or shipping containers (**Fig. 3**) that allow very little or no sunlight to reach the plants.

Depending on the latitude and the particular season, it is likely that electric lighting is needed to either supplement the naturally available sunlight for increased yields, to extend the day length, or to serve as the sole source of light. Since the human eye is not particularly good at assessing differences in light intensity and because humans can typically operate well in relatively low light intensities, we do not appreciate how much photosynthetic light plants need to grow and develop. In fact, plants need a lot more light than the average person would predict. Therefore, plant lighting is a critical component of urban crop production environments.

Fig. 1. Greenhouse supplemental lighting of rose cut flowers with high-pressure sodium (HPS) lamps

PHOTO: A.J. BOTH

Types of supplemental lighting systems

Three different types of electric lamps are commonly used in CEA: fluorescent (FL), high-intensity discharge (HID) and light-emitting diodes (LEDs). HID lamps can be further divided into high-pressure sodium (HPS) and metal halide (MH) lamps. The FL and HID lamps come in different sizes and wattages, but once installed they produce light with a fixed color spectrum. On average, FL lamps convert approximately 20 percent of the supplied electric energy into photosynthetically active radiation (PAR; discussed below) that plants use for photosynthesis. They are often used in growth or germination chambers designed for seedling production or tissue culture. The conversion efficiency increases to around 30 percent for HID lamps. The color spectrum of the light produced by MH lamps contains a little more blue than HPS lamps, and they are most often used in garden centers so that plants appear more true to color. HPS lamps have an effective light spectrum to promote flowering of long-day plants and photosynthesis.

Recent technology advances have made high-intensity LED lamps more attractive as photosynthetic lighting sources: They can be designed to produce a specific color spectrum, or they allow for the spectrum to be adjusted based on the needs of the plant. Unlike HID lamps, LED lamps produce little radiant heat, so they can be placed much closer to the plant canopy without damaging leaf tissue (**Fig. 4**). However, LED lamps still produce (convective) heat that needs to be removed to ensure efficient operation and maximum lifespan. LED lamps specifically designed for plant growth applications have recently surpassed the conversion efficiency of double-ended HPS lamps and are expected to reach even higher conversion efficiencies in the future. Most high-intensity LED lamps for horticultural applications contain red and blue diodes and may contain white diodes to allow humans to see the true color of plants.

Fig. 2. Light-emitting diode (LED) sole-source lighting of strawberries in a repurposed warehouse

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Supplemental lighting parameters

PAR refers to the waveband of light (between 400 to 700 nm) that is utilized by plants for photosynthesis. The amount of PAR a plant receives up to a species-specific level will increase photosynthetic rates and ultimately lead to improved growth, quality, and yield. Approximately 45 percent of the energy from the sun falls within the PAR waveband of 400 to 700 nm. Energy outside the PAR region is less photosynthetically active but may influence plant responses such as leaf/flower color (i.e., UV radiation can promote the concentration of anthocyanins), stem elongation (ratio of red:far-red light and blue radiation), flowering, and can also increase plant temperature (infrared radiation).

PAR is quantified in terms of instantaneous light intensity as the photosynthetic photon flux density (PPFD, units of $\mu mol \cdot m^{-2} \cdot s^{-1}$). Supplemental and sole-source light intensity guidelines vary by crop and by the amount of sunlight available.

Table 1. Recommended minimum and optimum DLI values for crops grown in CEA facilities

Crop	Minimum DLI ($mol \cdot m^{-2} \cdot d^{-1}$)	Optimum DLI ($mol \cdot m^{-2} \cdot d^{-1}$)
Bedding plants	8	10-12
Head lettuce	12	17*
Cucumbers	15	>30
Peppers	20	>30
Tomatoes	20	>30
Strawberries	17	>20

**At high light (i.e. fast crop growth) lettuce is very sensitive to tip burn (a physiological disorder due to insufficient calcium movement in the plant). Vertical air flow fans can be used to reduce the incidence of tipburn, otherwise a lower DLI target must be selected.*

Fig. 3. Light-emitting diode (LED) sole-source lighting of potted herbs in a shipping container

Generally, 50 to 90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of supplemental lighting from HPS lamps or LEDs are delivered to floriculture young plants and microgreens. Vegetables, herbs, and leafy greens are generally provided with higher supplemental lighting intensities of 100 to 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Light intensities for indoor sole-source applications are often double or higher as those crops receive no sunlight.

The term daily light integral (DLI) is used to describe the cumulative amount of PAR that a square meter area receives over a 24-hour period. The unit for DLI is moles of PAR per square meter per day ($mol \cdot m^{-2} \cdot d^{-1}$). The target DLIs to produce acceptable quality floriculture and high-quality young plants is 10 to 12 $mol \cdot m^{-2} \cdot d^{-1}$ (**Table 1**). For most cut flowers and greenhouse vegetables, the minimum target DLI to produce an acceptable quality crops is 15 $mol \cdot m^{-2} \cdot d^{-1}$. For fruiting vegetable crops increased DLI above 15 $mol \cdot m^{-2} \cdot d^{-1}$ will lead to increased crop yield. However, head lettuce is susceptible to the physiological disorder tip burn and becomes unmarketable when light levels exceed approximately 16-17 $mol \cdot m^{-2} \cdot d^{-1}$ (depending on cultivar and airflow).

For greenhouse production, there can be times when sunlight is excessive (e.g., resulting in tip burn in lettuce). For fruiting crops that can utilize higher DLIs, high amounts of sunlight may not be a problem but may make it difficult to control greenhouse temperature. Shading can be deployed all season long as a shading compound (ie., white wash) or a stationary net/screen, but the preferred method is a motorized retractable system that can be deployed automatically by the greenhouse environmental control computer when the light level exceeds a threshold value. Nighttime supplemental lighting of greenhouses can affect neighbors and thus be considered "light pollution" according to municipal code. Black out curtains can be used to mitigate such light pollution.

Lighting systems can be one of the highest capital costs in CEA. Growers are encouraged to work with a reputable horticultural lighting supplier to develop a lighting plan that will meet crop needs. Beyond the upfront cost and the energy efficacy (which determines the electricity cost) it is important to consider fixture shading and cooling, lifespan, warranty, maintenance and uniformity.

Fig. 4. Interlighting of high-wire tomatoes with LEDs

Some fixtures (i.e., FL and certain LED lamps) take up a large footprint for the amount of area they light, therefore these fixtures would provide excessive shade in a greenhouse environment and are better suited for sole source lighting applications. The lifespan of fixtures is usually rated based on the number of hours of operation to reach a certain decline in initial light output. For example, an L70 of 25,000 hours means that light output is expected to degrade to 70 percent of the original output after 25,000 hours of use. Depending on the crop and cost of electricity, it may be useful to replace a fixture or bulb even before the L70 is reached. Growers are encouraged to understand the warranty terms. Some fixtures are warranted for a given number of years and others based on the number of operating hours. Lighting suppliers can calculate a light map that displays the expected light intensity (PPFD) and uniformity at crop height given a particular layout of fixtures. Because lighting is such an important decision, get quotes from several suppliers and talk to colleagues for recommendations.

Finally, plant responses to light greatly depend on the crop being grown and specific environmental conditions (temperature, relative humidity, carbon dioxide concentration). Therefore, as with other production practices, it is highly recommended to conduct small-scale trials with lighting before considering large changes/investments. **pg**

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