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Commercial Greenhouse Production

Measuring Daily Light Integral in a Greenhouse

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In commercial greenhouses, several strategies can be used to help properly manage light levels throughout the day and seasonally. Some of the primary reasons why greenhouses manipulate light levels include temperature and irrigation management, photoperiod control, minimizing crop stress, and optimizing photosynthesis.

Supplemental lighting with high-intensity discharge (HID) lamps can increase the light intensity a crop receives and improve and accelerate its growth and development. Retractable shade curtains and whitewash can reduce and scatter light intensity to create a more desirable growing environment during high-light periods. This publication examines the characteristics of greenhouse lighting and describes one management option, daily light integral (DLI).

What Is Light and Why Is It Important?

Light is a form of energy called electromagnetic radiation. Electromagnetic radiation, whether from sunlight or HID lamps [e.g., high-pressure sodium lamps (HPS) or metal halide] varies in duration (energy over time), quality (wavelength or color), and intensity (the amount of light at each wavelength or color).

We will only focus on photosynthetically active radiation (PAR), which is light with a wavelength between 400 to 700 nm — this also happens to be the light people can perceive. Increasing energy in the PAR range increases plant photosynthesis, (the plant's most basic metabolic process). Each crop species has an optimal light intensity that maximizes photosynthesis and plant growth. When there is not enough light, growth and crop quality can decline; and if there is excessive light, photosynthesis and growth will not increase despite the expense of keeping the lights on.

Measuring Light

The most common units for measuring light are the foot-candle (primarily in the United States) and lux (primarily in Europe). It is important for growers to understand the limitations of these units. Both units provide an instantaneous light intensity at the time the reading is taken. As we all know, natural light levels are continuously changing and a single measurement in time does not accurately represent the amount of light a plant has received in a day.

Just as important, foot-candles are "photometric" units based on the amount of visible light detected by the human eye (primarily green light). That means foot-candles are focused on people and not appropriate for indicating plant photosynthesis.

Most horticultural researchers measure instantaneous light in micromoles (μmol) per square meter (m^{-2}) per second (s^{-1}), or: $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of PAR. This "quantum" unit quantifies the number of photons (individual particles of energy) used in photosynthesis that fall on a square meter (10.8 square feet) every second. However, this light measurement also is an instantaneous reading.



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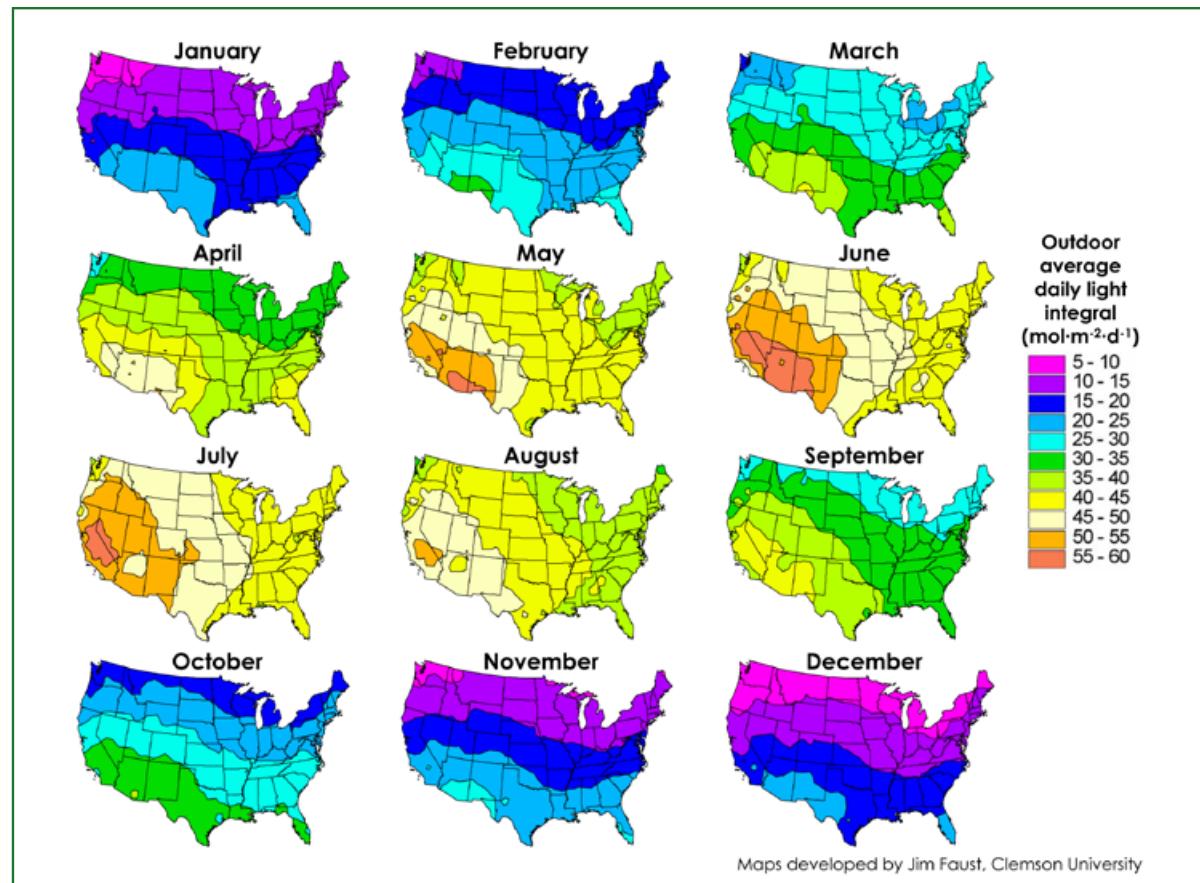


Figure 1. Maps of monthly outdoor DLI throughout the United States.

Source: Mapping monthly distribution of daily light integrals across the contiguous United States (Pamela C. Korczynski, Joanne Logan, and James E. Faust; Clemson University, 2002)

Daily Light Integral

Daily light integral (DLI) is the amount of PAR received each day as a function of light intensity (instantaneous light: $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and duration (day). It is expressed as moles of light (mol) per square meter (m^{-2}) per day (d^{-1}), or: $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ (moles per day).

The DLI concept is like a rain gauge. Just as a rain gauge collects the total rain in a particular location over a period of time, so DLI measures the total amount of PAR received in a day. Greenhouse growers can use light meters to measure the number of light photons that accumulate in a square meter over a 24-hour period.

Jim Faust and colleagues at Clemson University have developed maps of monthly outdoor DLI throughout the United States (Figure 1). These maps illustrate how latitude, time of year, length of day (photoperiod), and cloud cover influence DLI and vary from 5 to 60 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

In a greenhouse, values seldom exceed 25 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ because of greenhouse glazing materials and super-

structure, the season (which affects the sun's angle), cloud cover, day length (photoperiod), shading, and other greenhouse obstructions, such as hanging baskets.

The Importance of DLI in Greenhouse Production

DLI is an important variable to measure in every greenhouse because it influences plant growth, development, yield, and quality. For example, DLI can influence the root and shoot growth of seedlings and cuttings, finish plant quality (characteristics such as branching, flower number and stem thickness), and timing. Commercial growers who routinely monitor and record the DLI received by their crops can easily determine when they need supplemental lighting or retractable shade curtains.

This is especially true for growers in northern latitudes where the majority of crops are propagated from December to March and naturally occurring outdoor DLI values are between 5 to 30 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. Furthermore, these values can be 40 to 70 percent

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lower because of shading from greenhouse glazing, structures, and hanging baskets. These obstructions can result in an average DLI as low as 1 to 5 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

There are devices that automatically measure and calculate the DLI your greenhouse crops are receiving. One of these is the WatchDog weather station manufactured by Spectrum Technologies (Figure 2). This instrument is portable and should be placed next to your crop to determine the DLI for that particular area. Some models can be connected to download data automatically to a computer.



Figure 2. WatchDog weather stations contain light sensors and automatically calculate DLI.

Another method to measure DLI is to use a light quantum sensor connected to a data logger or computer (Figure 3). The sensor measures instantaneous light intensity (preferably in $\mu\text{mol m}^{-2}\text{s}^{-1}$) at some defined interval (such as once every 15 to 60 seconds), which allows you to calculate DLI. Table 1 on page 4 provides DLI calculations based on average hourly foot-candles or $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of PAR measurements. No matter which sensors you use, it is important to keep all light sensors level and clean to assure accurate readings.

DLI Recommendations

Plants grown under light-limiting conditions (a low DLI), typically have delayed growth and development. Research conducted at Michigan State University indicated that maintaining a DLI between 4 to 11 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ during stage 2 (callusing) and stage 3 (root development) accelerates propagation of petunia and New Guinea impatiens cuttings (Figure 4).

Experiments with these petunias and New Guinea impatiens have shown that, as propagation DLI increases, rooting, biomass accumulation (root and shoot growth), and quality (reduced stem elongation) generally increase, while subsequent time to flower generally decreases. Similarly, experiments with seedlings of celosia, impatiens, salvia, marigold, and



Figure 3. A light quantum sensor connected to a computer can measure and record instantaneous light levels throughout the day. These values can then be used to calculate the DLI received by the crops using Table 1.

viola showed that quality parameters at transplant increased when DLI increased up to 12 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

Based on this research, we recommend that greenhouse growers provide a minimum of 10 to 12 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ of light during the finish stage to produce many shade-intolerant floriculture crops. But remember, DLI requirements differ between greenhouse crops as outlined in Table 2 on pages 5-7. Some growers separate their floriculture crops by DLI requirements. Crops with a DLI requirement of 3 to 6 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ are considered low-light crops,

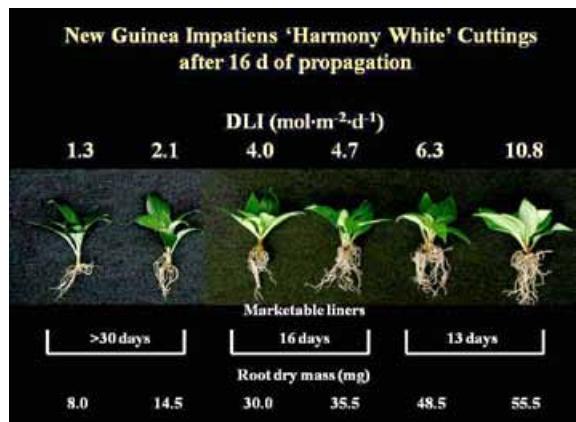


Figure 4. Influence of propagation daily light integral (DLI) on root development and liner marketability in New Guinea Impatiens (Lopez and Runkle, 2008).

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Table 1. Converting Foot-Candles to PAR and DLI

This table shows how to calculate from foot-candles to PAR ($\mu\text{mol.m}^{-2}\text{s}^{-1}$), and from PAR to daily light integral [DLI ($\text{mol.m}^{-2}\text{d}^{-1}$)] for sunlight and high-pressure sodium lamps (HPS).

Note that the conversion factor from foot-candles to PAR depends on the light source.

Step 1	Determine the average number of foot-candles per hour. Take the hourly foot-candle averages for the day, add them, and then divide this sum by 24.	For example, you have 24 hourly foot-candle readings: 0 + 0 + 0 + 0 + 5 + 12 + 21 + 40 + 43 + 159 + 399 + 302 + 461 + 610 + 819 + 567 + 434 + 327 + 264 + 126 + 15 + 4 + 0 = 4,408 foot-candles 4,408 foot-candles ÷ 24 hours = 184 foot-candles per hour
Step 2	Convert foot-candles per hour to PAR ($\mu\text{mol.m}^{-2}\text{s}^{-1}$) based on light source. Do this by multiplying foot-candles per hour by a factor for the light source. Sunlight has 0.20 foot-candles per $\mu\text{mol.m}^{-2}\text{s}^{-1}$. HPS lamps have 0.13 foot-candles per $\mu\text{mol.m}^{-2}\text{s}^{-1}$.	Using the same example as above, the PAR for crops receiving natural sunlight would be calculated like this: 184 foot-candles per hour x 0.20 foot-candles per $\mu\text{mol.m}^{-2}\text{s}^{-1}$ = 36.8 $\mu\text{mol.m}^{-2}\text{s}^{-1}$ For HPS lamps, the PAR would be: 184 foot-candles per hour x 0.13 foot-candles per $\mu\text{mol.m}^{-2}\text{s}^{-1}$ = 23.9 $\mu\text{mol.m}^{-2}\text{s}^{-1}$
Step 3	Convert PAR to DLI. Do this by using the following equation: PAR ($\mu\text{mol.m}^{-2}\text{s}^{-1}$) x 0.0864 The 0.0864 factor is the total number of seconds in a day divided by 1,000,000	For crops receiving natural sunlight: 36.8 $\mu\text{mol.m}^{-2}\text{s}^{-1}$ x 0.0864 = 3.2 mol·m⁻²·d⁻¹ For crops receiving HPS lighting: 23.9 $\mu\text{mol.m}^{-2}\text{s}^{-1}$ x 0.0864 = 2.1 mol·m⁻²·d⁻¹

6 to 12 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ are medium-light crops, 12 to 18 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ are high-light crops, and those requiring more than 18 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ are considered very high-light crops.

Supplemental Lighting

Under light-limiting conditions (such as during the winter in temperate climates), most greenhouse crops benefit from supplemental lighting. But remember, supplemental lighting is generally worthwhile only when increased photosynthesis leads to greater revenue (such as more turns of plugs, cutting liners or more cut flowers).

The practice of using HID lamps to supplement natural sunlight during periods of inclement weather or short days allows growers to increase productivity and plant quality. HPS or metal halide lamps typically provide between 250 and 750 foot-candles (33 to 98 $\mu\text{mol.m}^{-2}\text{s}^{-1}$).

HPS lamps that deliver 400 foot-candles (52 $\mu\text{mol.m}^{-2}\text{s}^{-1}$) for 12 hours provide a DLI of 2.3 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. This is a relatively small amount of light compared to the DLI provided by the sun (Figure 1). Without supplemental photosynthetic lighting, greenhouse crops in the northern half of the United States often receive insufficient light (<10 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) for several months of the year.

The percentage of U.S. greenhouse acreage using supplemental lighting is increasing, but it is still low — estimated at 10 to 20 percent in the northern half of the United States. Generally, the high investment and installation costs for HID lamps are a limitation for greenhouse growers.

In some areas of the country, electricity costs can be prohibitive during daily peak energy demands. In 2004, it was estimated that the average cost of supplemental lighting was \$0.052 per square foot per week across the United States. Some of the perceived drawbacks to using HID lamps for supplemental lighting, such as heavy ballasts and high energy consumption, are decreasing as lighting technologies improve.

In the future, light emitting diodes (LEDs) may replace HID lamps because they are more energy-efficient, reduce energy costs, provide more options for control of crop characteristics, are safer to operate, and reduce light pollution. However, supplemental lighting from LEDs is now extremely expensive and likely won't be practical in most greenhouse production situations until 2015 or beyond.

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Table 2. DLI Requirements for Various Greenhouse Crops

	Minimum acceptable quality
	Good quality
	High quality

1=Requires ample water to perform well at high-light levels.

2=Requires cool or moderate temperatures to perform well at high-light levels.

3=Stock plants perform well under higher light levels than finished plants.

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Table 2. DLI Requirements for Various Greenhouse Crops (continued)

Table 2. DLI Requirements for Various Greenhouse Crops (continued)

Species	Average Daily Light Integral (Moles/Day)														
	Greenhouse														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Zinnia															
Alstroemeria (cut flower)															
Capsicum (pepper)															
Chrysanthemum (cut flower)															
Dianthus (carnation)															
Gladiolus (cut flower)															
Lycopersicon (tomato)															
Rose (cut flower)															

Source: James E. Faust, *Ball Red Book*.

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