Calculating and Using Daily Light Integral (DLI): An Introductory Guide

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Introduction

Plants use energy from light to power photosynthesis, a process that converts light into sugars, serving as their primary source of energy. In turn, this captured energy supports nearly all life on Earth. That makes light one of the most important factors in agriculture, gardening, and life.

Despite its importance, light is often misunderstood, overlooked, or poorly managed. Whether you are a homeowner tending a few houseplants or a professional grower, learning how to measure and harness light can be a powerful tool in growing healthy, productive plants.

Why is Understanding Light Confusing?

One reason light can be confusing to understand is that we, as humans, interact with light differently than plants do. Our eyes are constantly adjusting to changes in the intensity of light. For example, in dim conditions, our pupils dilate, making a dark room seem brighter, even though the amount of light in that space remains unchanged. This natural adaptation makes it nearly impossible for us to correctly judge how much light a plant is receiving.

By contrast, plants can differentiate between different light intensities and qualities, which ultimately governs the efficiency of photosynthesis. This fundamental difference is why your eyes are not reliable tools for measuring light in a growing environment. To manage light properly, we must understand it from the plant's perspective rather than our own.

What Unit of Light Should I Use?

Because plants depend on the absolute quantity of light for photosynthesis, we need accurate methods to measure the amount of light they receive at any given time. Ideally, this means using units that directly relate to plant growth. Over time, the units used to measure light have changed as our understanding of plant biology and lighting technologies has improved.

Table 1. Common units used to quantify light intensity.

Name	Unit
Candela (cd)	"standard candle"
Lumen (lum)	cd·sr
Foot-candle (fc)	$\text{lumen}\cdot\text{ft}^{-2}$
Lux (lx)	$\text{lumen}\cdot\text{meter}^{-2}$
Joule (J)	$\text{kg}\cdot\text{meter}^{2}\cdot\text{second}^{-2}$
Watt (W)	$\text{kg}\cdot\text{meter}^{2}\cdot\text{second}^{-3}$
Photon flux density (PFD; 400-700 nm)	$\mu\text{mol}\cdot\text{second}^{-1}$
Photosynthetically active radiation (PAR; 400-700 nm)	$\mu\text{mol}\cdot\text{meter}^{-2}\cdot\text{second}^{-1}$
Photosynthetic photon flux density (PPFD; 400-700 nm)	$\mu\text{mol}\cdot\text{meter}^{-2}\cdot\text{second}^{-1}$
Daily light integral (DLI; 400-700 nm)	$\text{mol}\cdot\text{meter}^{-2}\cdot\text{day}^{-1}$

Historically, light intensity was often measured in foot-candles, a measurement based on the use of a standard candle to gauge light intensity. Thomas Edison even built his instruments to compare candle output with his early incandescent light bulbs (see Fig. 1). Although this was not ideal, as it relied on human vision rather than plant growth.

Lumen is another standard unit still used today, but like foot-candles, it is based on human vision and does not always translate well to plant growth. Watts and joules (i.e., units of energy) were also used in the past to describe light levels. While these units are useful for assessing how humans see light or how much energy a light source outputs, the units do not directly reflect the quantity of light that a plant can use for photosynthesis. In sum, it is not recommended to use units of candela, lumen, foot-candles, lux, Watts, or Joules when measuring light levels for plants.

Figure 1. Thomas Edison's photometer. The Henry Ford Museum - Greenfield Village.

Today, we use more plant-relevant units such as Photosynthetic Photon Flux Density (PPFD) and Daily Light Integral (DLI). These units correlate well with plant growth, allowing us to quantify light more accurately from the plant's perspective and support better decisions about lighting strategies, crop selection, and overall crop production.

Because foot-candle was a commonly reported unit for light intensity previously, it is possible to convert between foot-candles and PPFD, but the conversion factor depends on the light source. Table 2 contains some example conversion values for commonly used light sources in horticulture. A complete list can be found at (https://hortamericas.com/grower-resources/conversion).

Table 2. Conversion factors for foot-candles to photosynthetic photon flux density (PPFD).

Light source	Conversion factor
Sunlight	5.01
High-pressure sodium lamp	7.62
Metal halide	6.60
Cool-white fluorescent lamp	6.87

Using these conversion factors is quite simple. For example, full sun has a PPFD close to 2,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$. If we multiply 2,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ by 5.01, we can calculate full sun conditions to have 10,020 fc.

What do I Use to Measure Light?

Just as you would use a thermometer to measure temperature or a barometer to measure atmospheric pressure, we have instruments that allow us to precisely measure light intensity.

There are two main tools for measuring light intensity:

Quantum sensors: Quantum sensors, sometimes referred to as photosynthetically active radiation (PAR) sensors/meters, are devices that measure the PPFD. These sensors give readings in units of $\mu mol \cdot m^{-2} \cdot s^{-1}$. Standalone quantum sensors can range in price from less than $100 to over $1,000. In some cases, cell phones can have apps downloaded that use a phone's internal photodiode to measure PPFD and are typically the most cost-effective option. When paired with a computer to record measurements over time, quantum sensors give accurate information about light environments over the course of the day and throughout the year, offering powerful insights for commercial applications.

Spectroradiometers: Spectroradiometers function differently from quantum sensors, but they allow the user to measure light intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$) and also measure the color of light, which can be beneficial in some cases. The colors (i.e., blue, green, red, far-red, etc.) that constitute sunlight are relatively consistent; thus, spectroradiometers are less useful for measuring sunlight than light-emitting diodes (LEDs), which often come in varying combinations of colors. The primary drawback of spectroradiometers is their cost, which ranges from $1,000 to over $2,500. Consulting with LED manufacturers or extension professionals is a cost-effective way to gather spectral data and consider how light color affects plant growth.

However, the choice of measurement method and the level of precision required or desired ultimately depend on the application. A $20 phone app could provide useful information to homeowners, while a professional grower may choose to purchase many $500 sensors to improve large-scale horticultural production. Extension professionals can offer recommendations tailored to your individual needs and provide expertise on how to effectively measure light in your specific space.

What is Daily Light Integral (DLI)?

Daily Light Integral (DLI) is one of the most useful units for understanding the amount of light a plant receives. Commonly referred to as DLI, it represents the total amount of photosynthetic light a plant gets over the course of a single day. It is expressed in moles of light per square meter per day ($mol \cdot m^{-2} \cdot day^{-1}$) and integrates all the light between 400-700 nm. Notice the units are quite similar to PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$). To calculate the DLI, we first need to know the PPFD.

In simple terms, DLI tells you how much photosynthetic light reaches a plant over 24 hours, and this can be directly correlated to plant growth. Knowing the DLI can inform decisions about plant selection, lighting schedules, and overall plant care. Too little light can slow growth and reduce yield, while too much light can waste energy or even harm sensitive plants. Understanding and managing DLI can benefit both professionals and hobbyists alike.

The remaining sections of this guide explain how to calculate DLI and provide examples of how different plants respond to varying DLI levels. This article will also discuss strategies for adjusting and managing DLI in different growing environments.

What is the Correct DLI for My Plant or Crop?

It is helpful to put DLI into a context that people can more easily understand, and temperature offers a useful comparison. For instance, if the air is too cold, we might put on a jacket. If it is too hot, we might wear a T-shirt. Clothing choices often depend on personal preference, but most people tend to respond similarly to extremes. We also can check a thermometer to help us quickly decide what to wear, especially when the temperature is displayed in a familiar unit like Fahrenheit.

DLI can be used in a very similar way with a little practice. Just as people have temperature preferences, plants have preferred DLIs. These preferences are often based on the environments where the plants are native. Shade-loving species like *Hosta* grow best under lower DLI conditions (i.e., full-shade). Others, such as tomatoes or roses, thrive under higher DLIs, similar to what they would receive in full-sun conditions. The correct DLI should be selected based on the needs of each plant species.

Unfortunately, DLI is not a one-size-fits-all matter. The correct DLI depends on the type of plant, its age, and the production goals. There are several ways to determine the appropriate level. Local Extension professionals are a valuable resource, providing region-specific guidance based on research and experience. Additionally, numerous reliable sources are available online to assist in making informed decisions.

Table 3. Suggested average daily light integral (DLI; $mol \cdot m^{-2} \cdot d^{-1}$) for example crops.

Crop	Recommended DLI range ($mol \cdot m^{-2} \cdot d^{-1}$)
Seedlings	5–10
Cuttings	5–10
Micro-greens	9–12
Lettuce	12–17
Spinach	14–20
Parsley	10–15
Cilantro	15–20
Basil	15–25
Impatiens	8–12
Begonia	12–19
Geranium	12–19
Petunia	20-25
Tomato	20–30
Cucumber	20–30
Zucchini	20–30

Table 3 provides a partial list of examples, offering general DLI recommendations for various common horticultural crop types (Dou et al., 2018; Faust et al., 2005; Pramuk and Runkle, 2005). These values are meant to serve as a reference and may need adjustment based on specific conditions.

Notice that fruiting crops, such as tomatoes, have a much higher recommended DLI compared to crops grown primarily for their leaves or flowers, such as lettuce or petunia. This is because producing fruit requires significantly more energy. In some cases, the DLI needed for fruiting crops can be nearly double or even triple that of some leafy greens.

Lastly, and importantly, the “correct” DLI is somewhat subjective and not a fixed value. Managing DLI often involves added costs, so the economic considerations of adjusting light levels are just as important as a target DLI.

How do I Calculate DLI?

Calculating DLI can be done in two main ways, depending on where the light comes from:

When using electric lights:

When using electrical lights such as high-pressure sodium (HPS) or LEDs, it is possible to calculate DLI using two pieces of information. You will need to know 1) the PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) at the top of the canopy and 2) the number of hours the lights are operating. The equation below uses these two pieces of information to calculate DLI as follows:

$$DLI = \frac{PPFD * 3{,}600 * opperating\ hours}{1{,}000{,}000}$$

where 3,600 converts seconds to hours.

Now, take a practical example. If we have LEDs producing a PPFD of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and we turn the lights on for 16 hours a day, we have the following calculation:

$$DLI = \frac{200\ \mathrm{\mu mol \cdot m^{-2} \cdot s^{-1}} * 3{,}600 * 16\ hours}{1{,}000{,}000}$$

$$DLI = 11.5\ \mathrm{mol \cdot m^{-2} \cdot d^{-1}}$$

Based on our calculations, our LEDs would be powerful enough to grow a wide range of crops, from seedlings to bedding plants, but they would be insufficient for growing most fruiting crops. With this information, we can provide insight into what will and won’t grow well in particular situations, thereby limiting trial-and-error tests.

When Using Sunlight:

When using sunlight, we are at the mercy of the environment, which changes over the course of a single day and from one season to another. Similar to cold-hardiness maps produced by the USDA, there are useful tools to help determine what the average monthly DLI is in any given area. Figure 2 shows the average monthly DLI between July and December for each state using historical weather data from weather stations around the US. In Virginia, the average DLI ranges from 40-45 in July to 15-20 $mol \cdot m^{-2} \cdot d^{-1}$ in December (Fig. 2). Note that these values are for open spaces (free of trees and buildings), and the DLI in a residential space could be far lower in most cases.

It should be noted that while the USDA DLI maps are extremely useful, they can give imperfect estimates of average DLI, since microclimates can exist within any of these states. Measuring and monitoring light levels in your specific location will always yield the best information.

In the next section, we will cover examples of how to use the USDA DLI map to manage DLI.

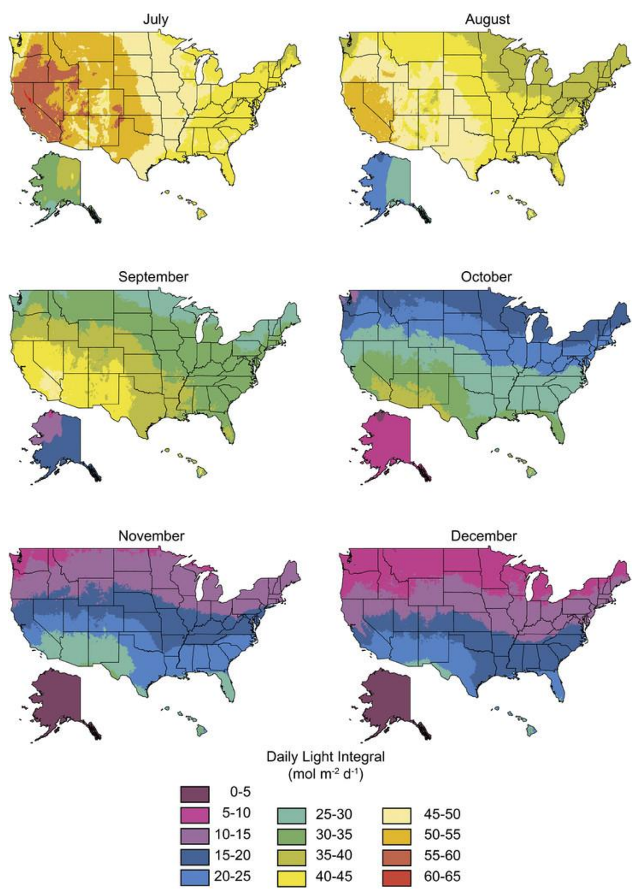

Figure 2. The average daily light integral (DLI) from July to December (Faust and Logan, 2018).

How do I Manage DLI?

Like temperature, the DLI can be both too low and too high for any given crop. There are several ways to adjust the DLI, whether growing in a greenhouse, nursery, or entirely indoors. We will cover how to manage DLI when it is too high or too low separately and provide several example situations for different growing systems.

If the DLI is too high in a nursery or greenhouse:

If the average DLI is too high, the primary management strategy in nurseries and greenhouses is the use of shade materials. Common options include shade nets, whitewash applications on greenhouse glazing, or physical shade structures made from rigid materials.

To lower DLI in a nursery or greenhouse, we need to know 1) the average monthly DLI (using the USDA DLI map or on-site data); 2) how much light the shade material blocks; and 3) the desired DLI for the crop. Shade materials are typically sold on a "percent shade" basis, which refers to the percentage of light the material blocks. For instance, 30% shade removes 30% of the incoming light. Below are two examples of how to calculate the correct percent shade based on this information using simplified math.

Nursery example: We want to grow Hydrangea macrophylla in Virginia in July when the average DLI is 40 $mol \cdot m^{-2} \cdot d^{-1}$. Hydrangeas grow well at a DLI close to 30 $mol \cdot m^{-2} \cdot d^{-1}$. Based on this information, we can calculate the appropriate percentage of shade for the material as follows:

$$1 - \frac{Desired\ DLI}{DLI\ outside} * 100 = needed\ \%\ shade$$

$$1 - \frac{30}{40} * 100 = 25\%\ shade$$

Based on this calculation, it would be ideal to use somewhere between 20% and 30% shade materials for hydrangea production.

Greenhouse example: We want to grow greenhouse lettuce in Virginia in July when the average outdoor DLI is 40 $mol \cdot m^{-2} \cdot d^{-1}$. Lettuce grows well at a DLI close to 15 $mol \cdot m^{-2} \cdot d^{-1}$. For greenhouse calculations, we need one additional piece of information: greenhouses typically receive 30% to 50% less light than open fields due to losses from the glazing and structural components. For this example, we will assume a 40% DLI loss, meaning that approximately 60% of the outdoor DLI reaches the plants inside. Based on this information, we can calculate the appropriate percent shade as follows:

$$1 - \frac{Desired\ DLI}{DLI\ outside * 60\%} * 100 = needed\ \%\ shade$$

$$1 - \frac{15}{40 * 60\%} * 100 = 38\%\ shade$$

Based on this calculation, it would be ideal to use shade materials that block approximately 40% of the light for greenhouse lettuce production in July.

If the average DLI is too low in a nursery or greenhouse

In some cases, even when taking full advantage of sunlight, the average DLI may still fall below the desired level for the crop you want to grow. The strategies that nurseries and greenhouses use to manage low-light conditions differ significantly.

Nursery example: Nurseries have limited options for managing DLI when sunlight is insufficient. However, insufficient DLI is less common in nurseries because low light conditions often coincide with unfavorable temperatures for plant growth. The primary management strategy is to carefully select crops and grow them at the appropriate times.

For instance, if we want to begin growing hydrangea as early in the year as possible, we can use the USDA DLI map to determine that the average DLI is sufficient by early March. Assuming air temperature is not a limiting factor, crops with lower DLI requirements could be grown even earlier. Therefore, timing the crop cycle to match average DLI levels is important for nurseries to avoid periods when light is too low to produce high-quality plants.

Greenhouse example: When the average DLI inside a greenhouse is too low, which is quite common, growers use electrical lighting such as HPS or LEDs to meet their desired DLI. Because greenhouses rely partially on sunlight, electric lights are used to supplement the deficit. This practice is commonly called "supplemental lighting." To deliver supplemental lighting correctly; several key pieces of information are needed: 1) the average monthly DLI; 2) the lighting system's PPFD at crop height; 3) how much light is lost through the greenhouse covering and structure; and 4) the desired DLI. Let's assume we want to grow greenhouse lettuce in December. Using simplified numbers, we know: 1) the average DLI in Virginia in December is 10 $mol·m^{-2}·d^{-1}$; 2) our LED system can deliver a PPFD of 200 $\mu mol·m^{-2}·s^{-1}$; 3) we are losing 40% of incoming sunlight; and 4) our desired DLI is 14 $mol·m^{-2}·d^{-1}$.

First, we need to determine the DLI deficit as follows:

$$DLI\ deficit = desired\ DLI - (average\ DLI\ outside\ * 60\%)$$

Based on our simplified numbers, we can determine the DLI deficit as follows:

$$14 - (10 * 60\%) = 8$$

From this equation, we know that our supplemental lighting system needs to deliver a DLI of 8 $mol·m^{-2}·d^{-1}$. Next, we can determine how long to operate our supplemental lighting system to deliver 8 $mol·m^{-2}·d^{-1}$ as follows:

$$Opperating\ hours = \frac{needed\ DLI * 1{,}000{,}000}{PPFD * 3{,}600}$$

$$\frac{8 * 1{,}000{,}000}{200 * 3{,}600} = 11\ hours\ each\ day$$

From this calculation, we can determine that the supplemental lighting system needs to operate for approximately 11 hours a day to achieve an average DLI of 15 $mol·m^{-2}·d^{-1}$. Table 4 presents common DLI values based on a PPFD = 200 $\mu mol·m^{-2}·s^{-1}$ and operating hours.

In the simplest case, a lighting system can be turned on continuously for 11 hours each day to meet our desired DLI for lettuce. While this option works, there are more efficient methods of delivering supplemental lighting.

Typically, supplemental lighting systems operate in the morning and evening to avoid providing light during the middle of the day, when the sun offers sufficient amounts of light for crop growth. Figure 3 illustrates an example of turning the lighting system on in the morning and evening when the ambient PPFD is less than approximately 200 $\mu mol·m^{-2}·s^{-1}$. Controlling lighting systems in this manner can be done manually or automated through greenhouse environmental controllers.

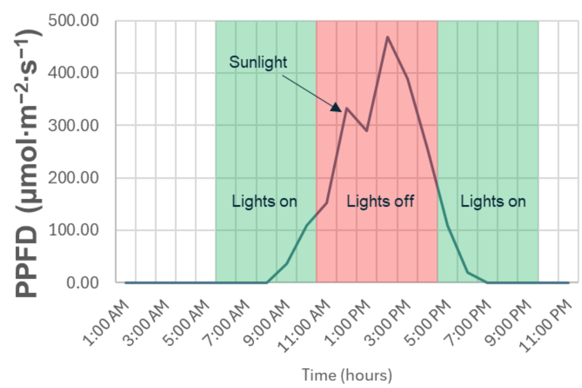

Figure 3. Example illustrating the use of supplemental lighting in the morning and evening when the ambient PPFD is low. Data taken at the Hampton Roads Agricultural Research and Extension Center greenhouse on Dec. 1, 2024.

Table 4. The calculated DLI ($mol·m^{-2}·d^{-1}$) is based on the number of operating hours and PPFDs of 50, 100, 150, 200, and 250 $\mu mol·m^{-2}·s^{-1}$.

Operating hours	50	100	150	200	250
2	0	1	1	1	2
4	1	1	2	3	4
6	1	2	3	4	5
8	1	3	4	6	7
10	2	4	5	7	9
12	2	4	6	9	11
14	3	5	8	10	13
16	3	6	9	12	14
20	4	7	11	14	18
22	4	8	12	16	20
24	4	9	13	17	22

If the average DLI is too low when using only electric lights:

Whether using HPS or LEDs, there are a few ways to increase the average DLI when using electrical lights as the sole light source, such as in a growth chamber or vertical farm.

Operating hours example: Similar to supplemental lighting in a greenhouse, we can commonly increase the number of hours electric lights operate to increase the DLI. Table 4 offers an example of how long to run lights to achieve a certain DLI based on several PPFDs.

Number of lights example: If running your lighting system for 18-20 hours at 100% power does not meet your desired DLI, it may be necessary to install additional lighting fixtures. Doubling the number of lights would about double the PPFD at canopy height.

Height adjustment example: In some cases, it is possible to move lights closer to plants to increase the DLI. Reducing the distance between the lights and the plants will significantly increase the PPFD (Fig. 4). Although this option is possible, it has a potential drawback. As lights get closer to plants, the overall uniformity of light distribution decreases. Put another way, when moving lights closer to plants, fewer plants can be effectively illuminated.

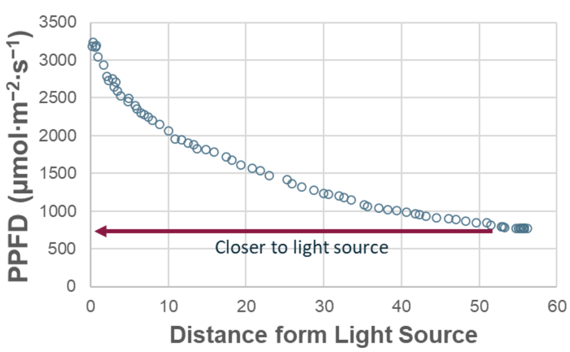

Figure 4. As the distance between a light source and a plant gets small (i.e., closer to one another), PPFD increases.

If the average DLI is too high when using only electric lights:

If the average DLI is too high when using LEDs, several simple corrective actions can be taken. These will be illustrated through several examples and are very similar to how to increase the DLI with electric lights.

Operating hours example: The easiest way to lower the DLI is to reduce the number of hours lights operate. For instance, if our lights produce a PPFD of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and we typically operate them for 16 hours a day, our DLI is 12 $mol \cdot m^{-2} \cdot d^{-1}$. If we want to start seedlings at a DLI of 9 $mol \cdot m^{-2} \cdot d^{-1}$, as shown in table 4, we would change the operating hours from 16 to 12 hours per day.

Height adjustment example: Moving lights further from plants decreases the PPFD (Fig. 4). Lights can be moved away from plants until a desired PPFD is achieved.

In some cases, such as vertical farms, the distance between plants and lights is very small (< 16 inches). In practical terms, as the plants are growing upwards towards lights, the PPFD at the top of the crop can increase significantly (Fig. 4). While this may be desired in some cases, exceedingly high PPFD can damage some plant leaves. If plants are growing too close to the lights, consider raising the lights.

Light output control example: Unlike older HPS lights, LEDs can be dimmed, effectively controlling how much light they provide. LED drivers can often receive a low-voltage signal (i.e., 0-10V) to control the light's output. Based on this principle, DIY LED controllers can be fabricated. Alternatively, some come with dials that allow for easy control of the output.

Luckily, LED output is linearly related to PPFD, which makes controlling LEDs straightforward (Fig. 5). For example, assume we have an LED that provides a PPFD of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at 100% power. To reduce the PPFD to 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$, we would simply adjust the LEDs to 50% power. This relationship can be determined for any LED fixture.

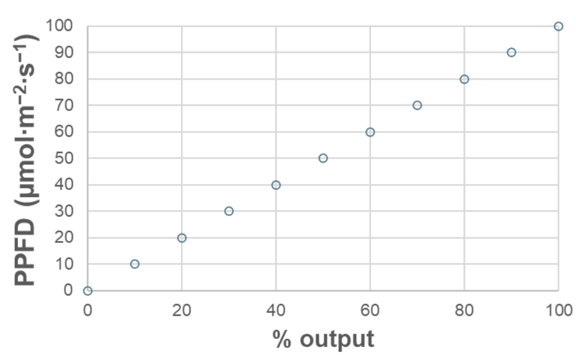

Figure 5. LED output is linearly related to PPFD. 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ is an arbitrary number. The maximum PPFD will depend on the light source and the distance from the light source.

Summary

Knowing how to manage light is a critical factor in producing high-quality plants. The most useful way to quantify how much light a plant receives is by using the correct units: PPFD and DLI. Once light is measured, growers can select crops more effectively and begin managing light levels to improve cultivation practices. While this guide is intended as an introduction to the topic, more advanced aspects of light management exist that will further improve cultivation practices. Consulting with Extension or industry experts is a cost-effective way to leverage this information and improve your growing practices.

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Additional Resources

Converting foot-candles to PPFD: https://www.apogeeinstruments.com/conversion-ppfd-to-foot-candles/.

Finding DLI by location: https://dli.suntrackertech.com

Visit Virginia Cooperative Extension: ext.vt.edu

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