WP001 - Comparison of Grow Light Sources

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Introduction

The selection of an appropriate light source is important because light is the single most important factor in plant growth. No other environmental parameter has as strong an influence.

Plants are sensitive to light energy at specific wavelengths. The rate of photosynthesis is driven by the quantity of photons with wavelengths between 400 and 700nm. This range of wavelengths is called the Photosynthetic Active Radiation (PAR) region[1].

[1] Pearcy, R.W., Ehleringer J., Mooney, H.A., and Rundel P.W. *Plant Physiological Ecology; Field Methods and Instrumentation*. Chapman and Hall, 1989. ISBN 978-94-009-2221-1

There are a few additional terms in the horticulture industry that should be defined. Photosynthetic Photon Flux (PPF) is measured in $\mu mol/sec$ defines the total number of photons emitted per second in the PAR region and mathematically is defined as:

$$\mu mol/s = 10^6 \times \sum_{\lambda_i=400}^{700} \frac{P(\lambda_i) \times \lambda_i}{h \times c \times N_A} \qquad (1)$$

P = radiometric power at the wavelength of interest, λ = wavelength of light, h = Planck's constant ($6.626 \times 10^{32} m^2 \cdot kg/sec$), c = the speed of light ($2.998 \times 10^8 \cdot m/s$), and N_A = Avogadro's constant ($6.022 \times 10^{23}/mole$). This equation describes the total flux, but what is important is the amount of energy that reaches the plant canopy.

Photosynthetic Photon Flux Density (PPFD) is measured in $\mu mol/m^2 \times sec$. It represents the number of photons that reach the plant within the PAR region over a given area. PPFD declines exponentially as the distance between the light source and the plant surface increases.

The Daily Lighting Integral (DLI) describes the minimum amount of light a plant needs in order to meet its basic biological needs.[2] This value is species dependent and is defined as:

[2] J.E. Faust. *Ball Redbook: Crop Production*. Ball Publishing, 2001. ISBN 978-18-830-5268-3

$$DLI = PPFD \times 3600(sec/hr) \times photoperiod(hrs/day) \qquad (2)$$

Different plants require different light energy and wavelength combinations. If a light source does not have sufficient light output in the wavelengths that the plant absorbs, then plant growth will be limited. If a light source produces energy in wavelengths that the plant does not need, then money is being wasted by producing light that goes unused. Additionally, unused light generates heat that must be removed from the plant's environment by an air conditioner or some other environmental control method, which consumes additional resources.

Operating cost is a strong factor to consider when selecting a light source. For example, lighting and air conditioning costs account for approximately 35% of the total cost for greenhouse tomatoes. This reinforces the importance of selecting a light source that matches the light energy and wavelength combination of a particular plant species.

The primary pigment for photosynthesis in plants is called Chlorophyll-A. It has absorption peaks at 430nm and 662nm and is required for all photosynthetic organisms except photosynthetic bacteria. The secondary pigment required is called Chlorophyll-B. It has absorption peaks at 453 and 642nm. Chlorophyll-B is required for all plants and green algae[3]. The figure below shows the relative light intensity vs. the wavelength that most plants need.

[3] Luis Aceña. *Winning in Horticulture with LUXEON SunPlus Series*. Lumileds Holding B.V, 2016

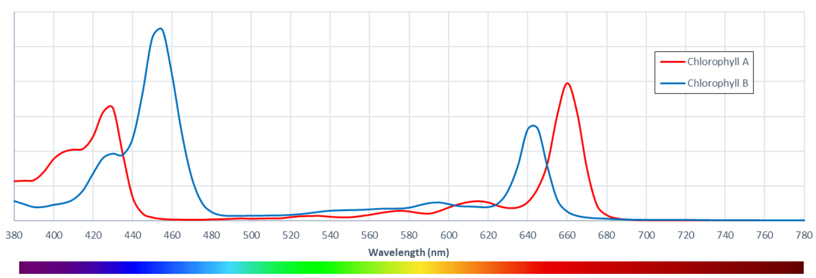

Figure 1: Spectral response of Chlorophyll-A and Chlorophyll-B as a function of wavelength. *Notice that both have peak response in the blue and the red regions.*

Sunlight

Sunlight has two major benefits: it has all the wavelengths plants need and it is free. Sunlight has high energy across the entire PAR region. Plants have evolved and adapted to the sun's spectral output over thousands of years. So, no wonder it is a good source of light for plants.

There are a few downsides, however. First, there is night time. Other light sources can stay on more hours each day, providing more hours of photosynthesis and plant growth. Secondly, there are cloudy days, where the reduction of visible light and reduces plant growth. Lastly, there is air pollution. Many areas of the world have enough air pollution that photosynthesis is reduced, at least on some days.

Solar Tubes

Solar tubes are a new technology. They enable the use of natural sunlight in indoor facilities and otherwise share the same advantages and disadvantages of sunlight. Solar tubes have a higher initial cost

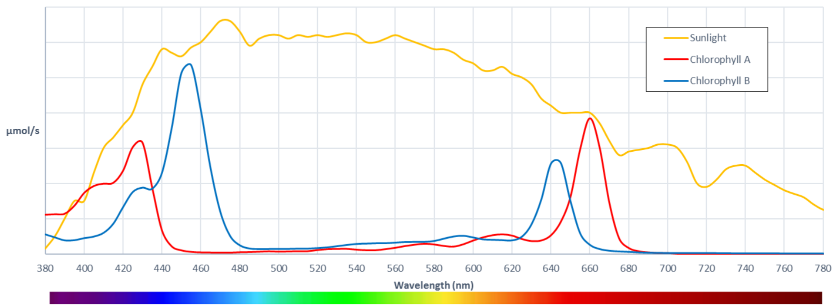

Figure 2: Spectral content of natural sun light.

than other lighting fixtures. However, they offer a significantly lower lifetime cost of ownership. The tube placement in a grow facility is limited by the rooftop geometry.

Metal Halide Quartz (MH)

Metal Halide is a type of High Intensity Discharge (HID) lamp. It generates an electric arc through a gaseous mixture of mercury and metal halides, which are compounds of metals with bromine or iodine. It has an arc tube made of quartz. MH has a high energy spectrum and cooler operating temperature than HPS. Some MH lamps have strong UV content, while others have a coating to filter it out. It has lower light output than HPS for equivalent electrical power, with an efficacy of 75-100 lumens per watt. It has the shortest lifetime of all light fixtures with a lamp life of only 6-15K hours.

Figure 3: Several examples of metal halide lamps.

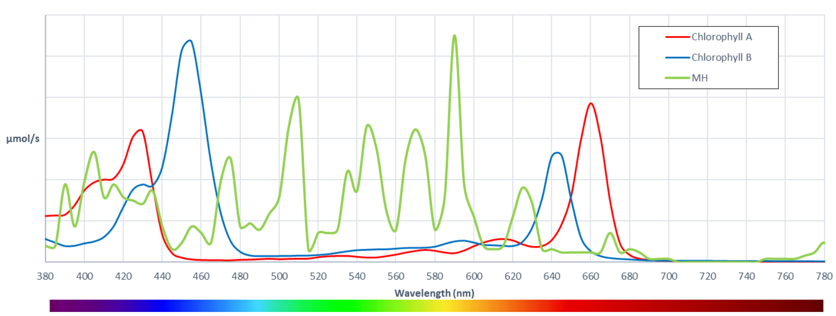

Figure 4: Spectral content of a metal halide lamp. *Notice the energy content between 480nm and 600nm. This is not the ideal absorption spectrum of Chlorophyll-A and Chlorophyll-B.*

Ceramic Discharge Metal Halide (CDM)

CDM is similar to the MH lamp, but uses a ceramic arc tube rather than quartz. It is often referred to as Ceramic Metal Halide (CMH). The ceramic material allows operating the arc tube at higher temperatures, which enables higher light output and higher efficiency. It is

10-20% more efficient than MH with an efficacy of 80-120 lm/watt. It has a balanced spectrum with good UV output and, while the arc tube runs at a higher temperature, it has a cooler overall operating temperature than both MH and HPS.

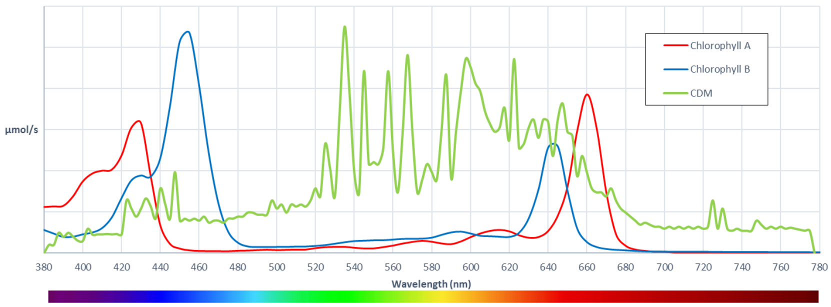

Figure 5: CDM spectrum (CDM-TMW Elite 315W/930, Philips Lighting). *Notice the energy content between 520nm and 620nm.*

The spectrum of MH does not provide much light energy in the chlorophyll absorption peaks. They have a relatively short lifetime of only 24K hours and since only lower wattage bulbs are available, more fixtures are required.

Light Emitting Ceramic (LEC)

LEC is a manufacturer-specific line of CDM grow lights. They have the same advantages and disadvantages as CDM.

High Pressure Sodium (HPS)

HPS lights are one of the most common agricultural lighting fixtures and produce warm white light. They have the highest photon output of HID lights except double-ended HPS and have a long lifetime. HPS lights provide very little energy in the Chlorophyll absorption peaks, have a higher operating temperature than MH or CMH, and are deficient in UV.

Figure 6: Example of a high pressure sodium lamp.

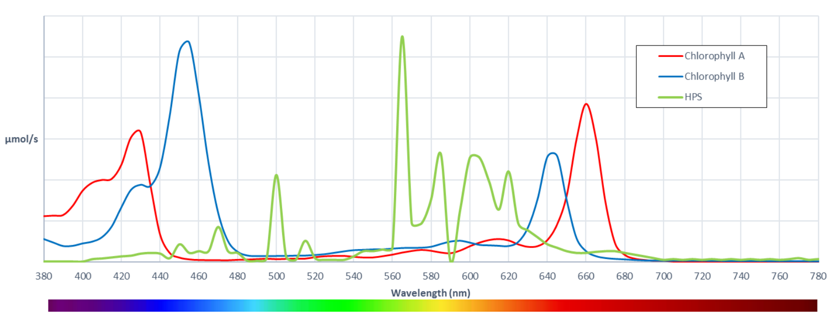

Figure 7: Spectral content of a high pressure sodium lamp. *Notice the energy content between 560nm and 620nm.*

Double-Ended High Pressure Sodium

Double-ended High Pressure Sodium lamps have the highest output of all HID lamps. They have warm color temperatures ranging from 2000K to 3000K, favoring the flowering stages of growth. They require special fixtures and ballasts, but provide high light output and a long lifespan. While they provide more light output than regular HPS, they provide relatively little energy in the Chlorophyll absorption peaks.

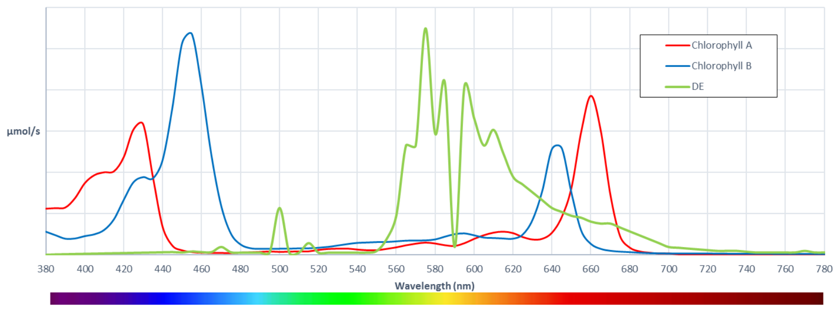

Figure 8: Double-ended HPS spectrum (Philips Master GreenPower Plus HPS).

Dual-Arc Grow Lights

These lights contain both metal halide and high pressure sodium arcs within the same bulb. They provide the benefits of both light technologies. They provide good efficacy, but have a short life and produce a high thermal load.

LED

LED grow lights are the most promising light source for horticulture. Of all artificial light sources, they provide the longest lifetime, lowest total cost of ownership, and the lowest operating temperatures. LEDs enable a wide dynamic range of spectrum and intensity changes. They can be easily and quickly controlled, enabling unique lighting recipes.

Most LEDs emit light at specific wavelengths so the light produced can be tuned to closely match the wavelengths that the plant needs. This minimizes the amount of wasted light and minimizes heat generation. LED fixtures provide blue light in the 415 to 470nm range for vegetative growth. This promotes strong root growth and intense photosynthesis. Often only blue light is used during the early phases of plant growth, for starting seedlings and when flowering is not desired.

Figure 9: Example of a variable spectrum LED grow light.

Red light in the 640-670nm range is provided for stem growth, flowering, and fruit production. This spectral range encourages stem growth and increases the rate of seed germination. This is key for flowering and fruit production. Some fixtures include far red light in the 730-740nm range for photoperiodism. This light range controls the plants clock mechanism. It can be used to trigger flowering.

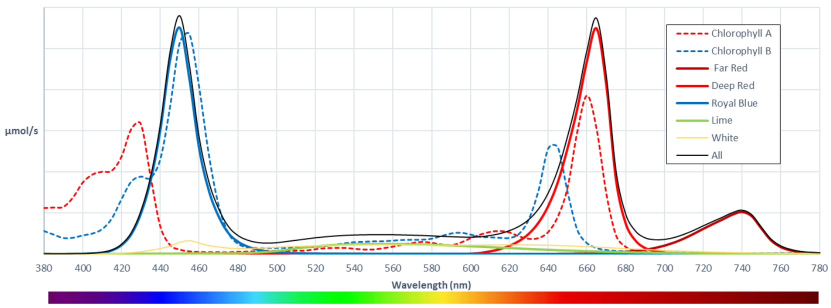

Figure 10: LED spectrum (Nate Controls L1). *Notice that the spectral response overlays the absorption spectrum of Chlorophyll-A and Chlorophyll-B.*

Lime and white light are often included to provide broad spectrum light for accessory pigments. These colors also provide a great visual inspection light that enables workers to see a better color rendition of the plant. This light also reduces fatigue in workers. LED fixtures are typically deficient in UV and IR light.

Light Emitting Plasma

Light Emitting Plasma lamps have a broad spectrum that is most like sunlight. This is a type of gas discharge lamp that is energized by RF power.

It provides UVA and UVB light output. These lights have relatively low light output, a 50K hour rated lifetime, and a higher cost of ownership than other grow light sources. They produce low heat and have low IR radiation.

Figure 11: Example of light emitting plasma lamp (Gavita Pro 270e LEP).

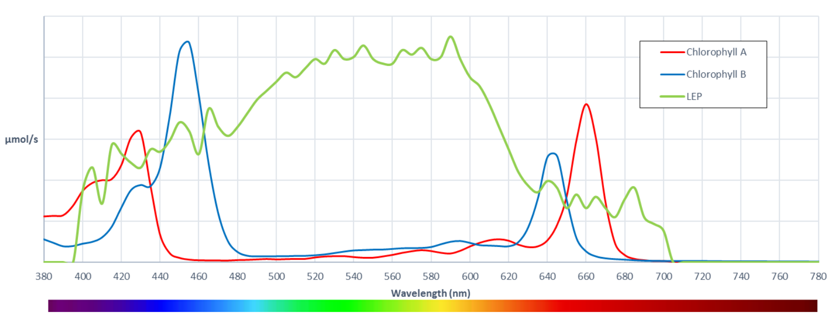

Figure 12: Light emitting plasma spectrum (GRO-75 by Luxim). *Notice the very broad spectral response.*

Fluorescent

Fluorescent lamps have a diffuse spectrum and are widely available with different variations for performance and light output. Some lamps provide high UV output. Because they are so widely available, they have a low cost of ownership. They are available with efficacy ranging from 50 to 100 lm/watt, and have a lifetime ranging from 30K-60K hours.

Figure 13: Example of fluorescent lamps

Fluorescent lamps have low-photon output compared to other light sources. Only a small percentage of the total light energy for fluorescent lamps is in the wavelengths needed for the chlorophyll absorption peaks. Most of the light energy is in the green region, which is generally reflected by the plant.

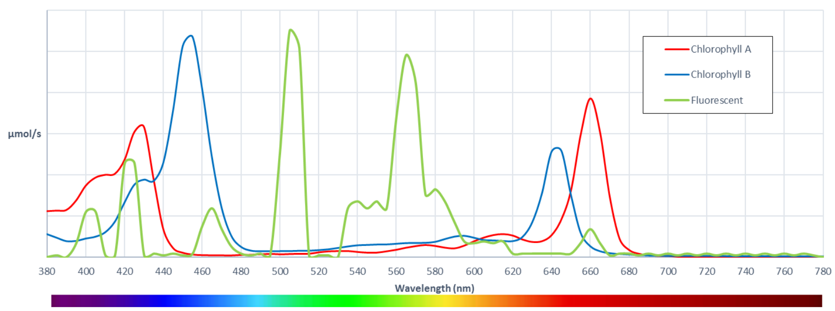

Figure 14: Fluorescent lamp spectrum.

Because they contain mercury, many fluorescent lamps are classified as hazardous waste. They should be recycled or segregated from the general waste stream for safe disposal as recommended by the EPA.

Summary

There are many grow light options to choose from and there are advantages and disadvantages with each. Even within each light category, there are a number of options available from different manufacturers and their specifications can vary widely[4]. So, when you are deciding which grow light is best for you, be sure to look at the specifications carefully.

[4] A. Wade. *The Science of Light; Exploring Photosynthesis to Achieve Optimum Growth and Potency*. CannaGrow Expo, Denver, CO, 2016

	Ideal for Vegetative	Ideal for Flowering	Full Spectrum	UV
LED	x	x	x	-
Sunlight	x	x	x	x
Solar Tube	x	x	x	x
Metal Halide - Quartz (MH)	x	x	-	x
Metal Halide - Ceramic (CDM or LEC)	x	x	x	x
High Pressure Sodium (HPS)	x	x	-	-
Double-Ended High Pressure Sodium (DE-HPS)	x	x	-	-
Light Emitting Plasma (LEP)	x	x	x	x
Florescent	x	-	-	x

Table 1: Summary of common lighting qualities across different lighting technologies.

	Efficacy (μ-mol/Joule)	PPF (μ-mol/sec)	Lifetime (k-hours)
LED	1.95	1600	50
Sunlight	n/a	n/a	n/a
Solar Tube	n/a	n/a	n/a
Metal Halide - Quartz (MH)	1.30	1334	6 to 15
Metal Halide - Ceramic (CDM or LEC)	1.46	491	24
High Pressure Sodium (HPS)	1.02	1090	20
Double-Ended High Pressure Sodium (DE-HPS)	1.70	1767	20
Light Emitting Plasma (LEP)	-	-	10
Florescent	0.95	374	20 to 60

Table 2: Summary of common lighting performance metrics across different lighting technologies.

	Lowest Cost of Ownership	Lowest Cost of Maintenance
LED	x	x
Sunlight	x	x
Solar Tube	x	x
Metal Halide - Quartz (MH)	-	-
Metal Halide - Ceramic (CDM or LEC)	-	-
High Pressure Sodium (HPS)	-	-
Double-Ended High Pressure Sodium (DE-HPS)	-	-
Light Emitting Plasma (LEP)	-	-
Florescent	x	x

Table 3: Summary of ownership and maintenance costs across different lighting technologies.

References

Luis Aceña. *Winning in Horticulture with LUXEON SunPlus Series*. Lumileds Holding B.V, 2016.

J.E. Faust. *Ball Redbook: Crop Production*. Ball Publishing, 2001. ISBN 978-18-830-5268-3.

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