SPECIALTY LIGHTING APPLICATIONS

For Horticulture

THRIVE AGRITECH

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INTRODUCTION

Lighting solutions for horticultural applications have been relatively stable since the inception of the high pressure sodium (HPS) lamp in the 1960s. However, the industry is currently experiencing a renaissance as advances in light emitting diodes (LEDs) have enabled innovative ways in which light can enhance plant productivity.

Most people think only of photosynthesis when discussing the topic of grow lights. In this technical brief we examine niche applications for enabling photosynthesis such as tissue culture, aquaponics, and algae. We also investigate how light can be used for non-photosynthetic purposes such as preventing plant disease and increasing worker productivity without causing night interruption. Finally, we dive into the topic of good manufacturing practices (GMP) to better understand the attributes of lighting systems that conform to the quality standards of medical product production facilities.

TISSUE CULTURE LIGHTING

Tissue culture is the growth of cells from tissue originating from a multicellular organism in an artificial medium separate from the parent organism (i.e., *in vitro*). Tissue culture can be performed using cells that come from animals or plants. Plant tissue culture (photo right) is conducted under sterile conditions on a nutrient culture medium to produce clones of a plant in a method known as micropropagation. Micropropagation is used to multiply plants that often have been genetically modified or bred through conventional plant breeding methods. It is also used to provide a sufficient number of plantlets for planting from a stock plant which does not produce seeds or does not respond well to vegetative reproduction. One of the primary benefits of plant tissue culture is the ability to create exact copies of plants that produce particularly good flowers, fruits, or have other desirable traits.

Plant Tissue Culture

Plant tissue culture was originally used in the production of orchids in the 1950s, and the technique has been adopted by many agricultural species since then including fruits, vegetables, and flowers. As the scale and sophistication of the cannabis industry in the United States has developed over the past decade, the practice of tissue culture has become ubiquitous. Historically, cannabis growers relied on cloning for plant propagation. They would take cuttings from "Mother" plants to preserve genetics and desirable plant characteristics. But tissue culture has a host of advantages over cloning. Tissue culture yields at least 2X-3X more plants than cloning, requires less physical space, and is less susceptible to genetic variation. Further, tissue culture tends to produce cleaner, healthier, more efficient plants since clones have greater exposure to disease, pests, and infections.

Cannabis Tissue Culture

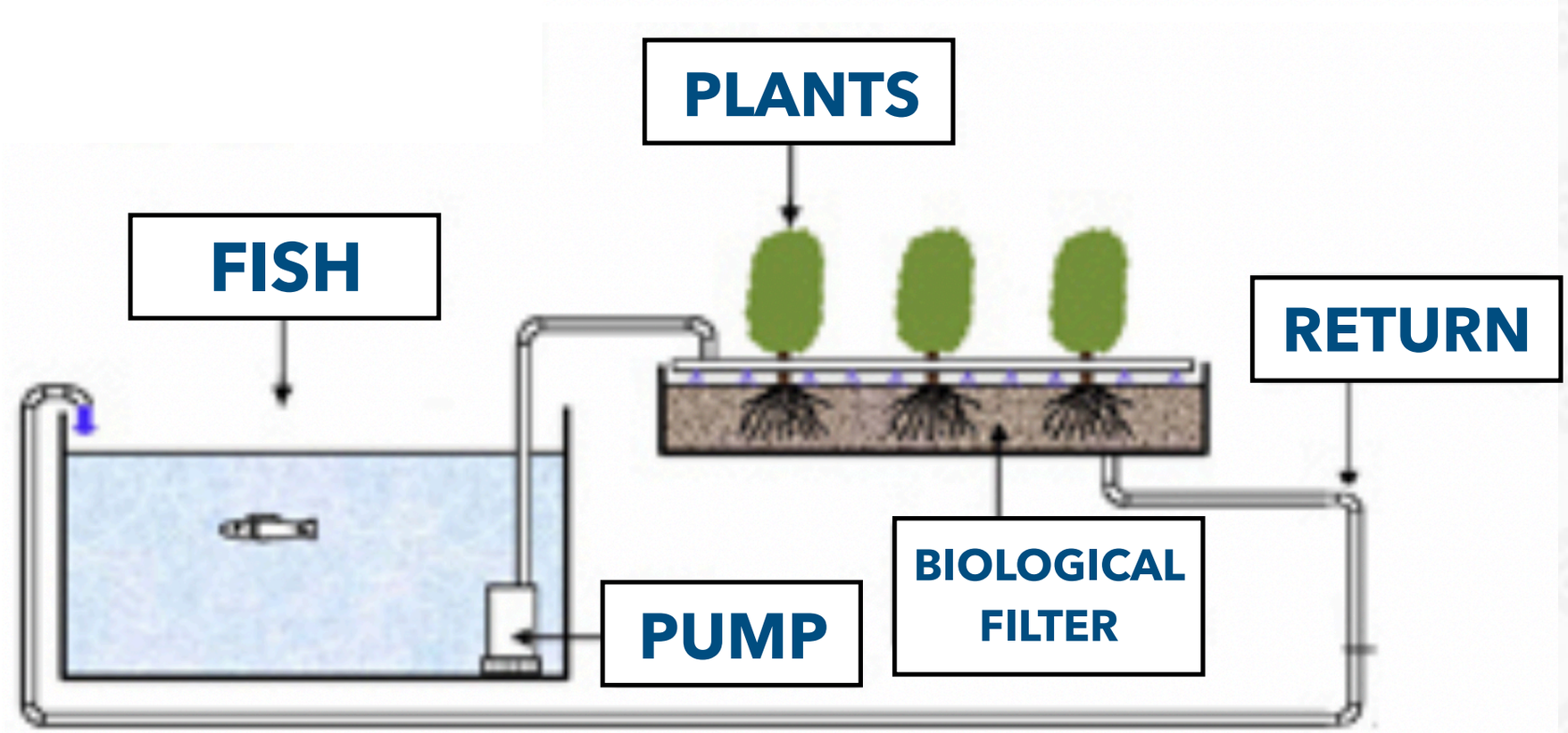
But tissue culture is not immune to disease and contamination, and careful consideration must be taken when setting up a tissue culture grow operation. Growers need to ensure the equipment that surrounds the tissue culture plants do not become contaminated, thereby compromising plant development and health. Due to the need for a near-sterile environment, tissue culture is normally conducted indoors, which means electric lighting is required.

Fluorescent tubes have traditionally been used as the light source, but most growers are converting to LEDs for several compelling reasons. Thrive Agritech recently supplied Stevens Green (Ontario, Canada) with LED lights for cannabis tissue culture. According to the company, they selected Thrive's LED lights because they are easy to clean, simple to install, dimmable and have full spectrum white light. Dimmability was important to Stevens Green as early propagation requires low light levels, so care must be taken not to stress the plant. Tissue culture plants typically require light intensity between 50-150 µmols/m^2/sec. Fluorescent lights are not dimmable, and they have higher heat content in the light beam that can stress/burn the young plants. And from their experience, tissue culture plants respond better (better root development) to the full white light spectrum as opposed to "pink" LED lights available in the market. Stevens Green is seeing excellent results from their tissue culture grow room, and this can only help them generate healthy plants and a healthy bottom line for the company.

Tissue Culture Grow Room

LIGHTING FOR AQUAPONICS

Aquaponics is the integration of hydroponics – growing plants without soil – and aquaculture – fish farming. It's a symbiotic ecosystem that uses the waste produced by fishes as nutrients for growing plants. The fish waste is broken down by nitrifying bacteria initially into nitrites and subsequently into nitrates, which are absorbed by plants as nutrients. The clean water is then recirculated back to the fish tank and the cycle repeats (figure below).



Aquaponics provides for an efficient way of growing leafy greens and vegetables in an eco-friendly manner. For example, Aquaponics uses 90% less water than traditional farming, while simultaneously producing on average six times more yield per square foot. Operators of aquaponics facilities typically sell both the plants and the fish. Fish species commonly farmed include tilapia, salmon, bass, carp, brim, and koi. According to Zion Market Research, the global aquaponics market was valued at approximately $0.5 billion in 2017 and is projected to increase to $1.3 billion by 2024, representing a compound annual growth rate of 10%. Some of the key companies participating in aquaponics market include The Aquaponic Source, Aquaponic Lynx, Greenlife Aquaponics, Aqua Allotments, Backyard Aquaponics, UrbanFarmers, ECF Farmsystems, Nelson and Pade, My Aquaponics, and Ultrasonics Canada Corporation.

For plants to remain viable at an aquaponics farm, photosynthesis is required, which means there must be a source of light. Light can be natural (sun) or electric, or a combination of both. Frequently, aquaponics operations are located in greenhouses where natural sunlight is abundant. But during winter months electric light is used to supplement the sun to ensure plants continue growing at an ideal pace. There are several considerations when choosing supplemental lighting including the optimal lighting technology, spectrum, installation, reliability, and cost. LED technology has become a popular choice recently due to increasing energy efficiency and lower up-front cost. Other lighting technologies are fluorescent, metal halide and high-pressure sodium (HPS). While the initial cost of these other technologies is lower than LEDs, operating costs are substantially higher due to lower energy efficiency. In addition, fluorescent, metal halide and HPS have much higher heat content transmitted to the plant, which can cause yellowing or burning of the plant if the light source is too close.

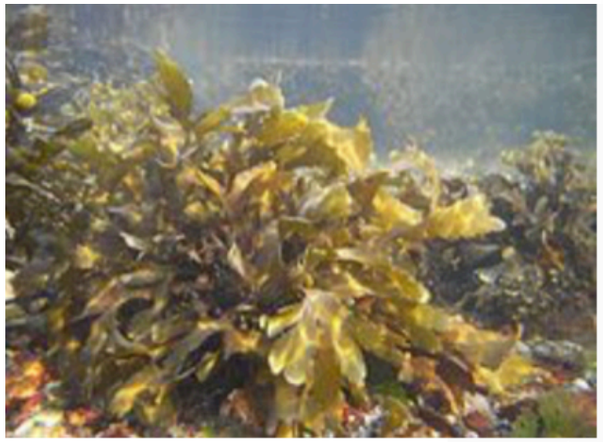
BellaVita Aquaponics Greenhouse

Thrive Agritech recently supplied LED lights for aquaponics to BellaVita Farm in Brookeville, Maryland. The farm produces a wide variety of leafy greens, tomatoes and microgreens for sale to nearby high-end restaurants.

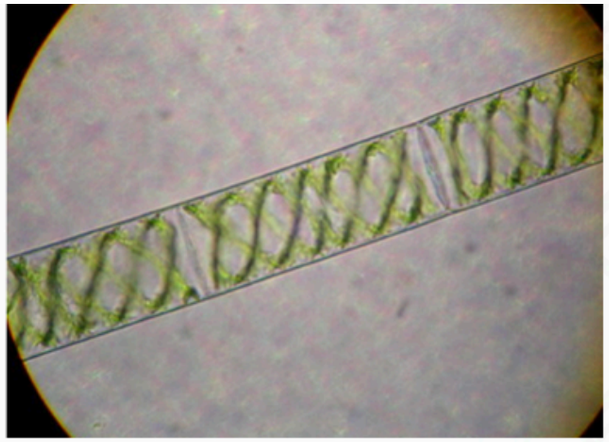
To maximize crop production per square foot within the greenhouse, BellaVita uses a multi-tier growing method as shown in the photos. The LED lights were installed on the lower tier, which is shaded from the sun. The lights were specified by The Aquaponics Source, a leader within the aquaponics industry. According to Rob Tolette, Director of Sales and Product Development at The Aquaponics Source, there were several important factors that went into the decision to specify Thrive Agritech's lights for BellaVita. First, they wanted a full spectrum white light that had wavelengths like the sun. Some LED lights are pinkish in color, which can make it difficult to assess plant health while inspecting. Rob stated that Thrive's lights met other important criteria such as being IP66 rated (water resistant) and energy efficient. Further, he said "The modularity and snap & go connections made installation easy." Rob reports that the BellaVita crops are flourishing with the lights and they are looking forward to years of continued success.

ALGAE GROWTH WITH LED LIGHTING

Algae is defined as a large and diverse group of photosynthetic eukaryotic organisms typically found in damp places or in water. Most algae are autotrophic in that they make organic compounds from simple molecules by taking in energy from the environment such as the sun. Algae play significant roles in aquatic ecology. Microscopic forms that live suspended in water are called phytoplankton, and provide the food base for most marine food chains. The most complex marine algae are seaweeds, while the most complex freshwater forms are Charophyta, a division of green algae which includes spirogyra and stoneworts.



Seaweed



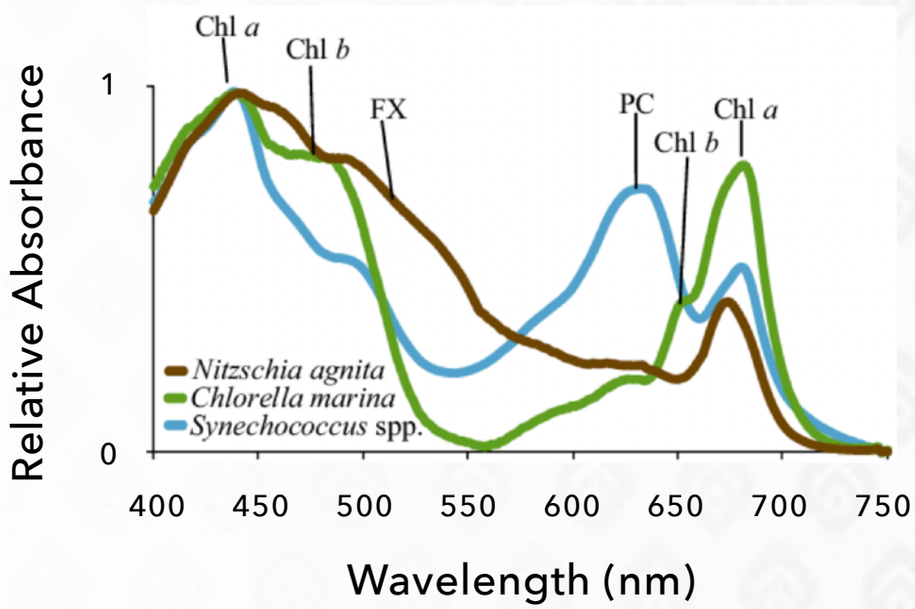
Spirogyra

Stoneworts

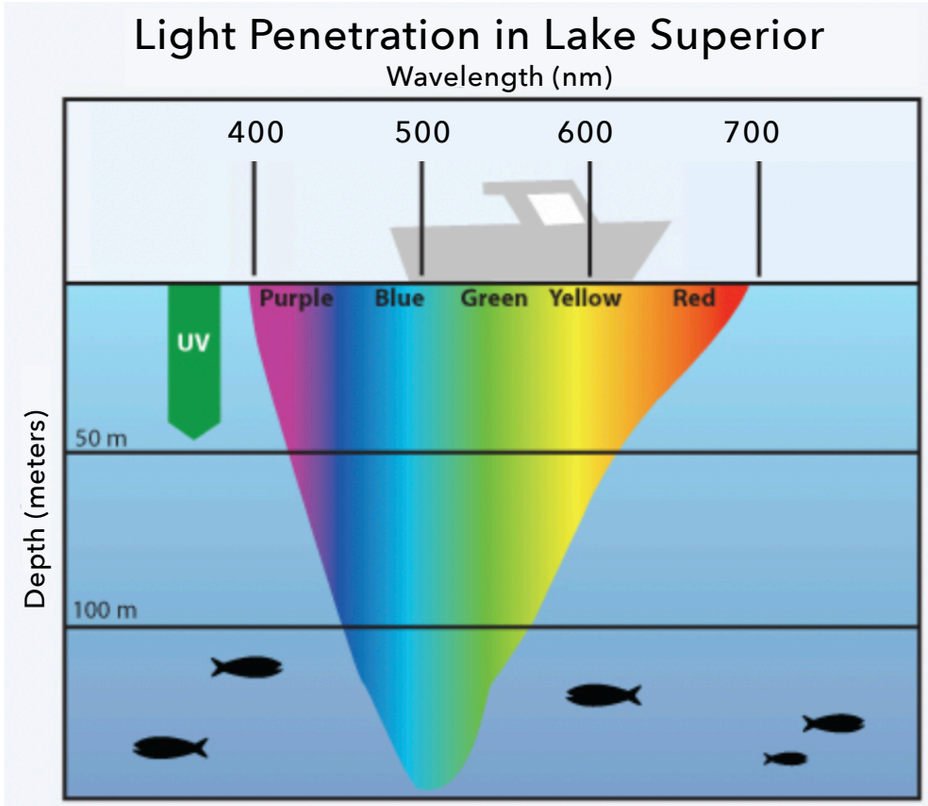
Farming of algae, also known as algaculture, is on the rise globally. Algae contain high levels of oils, carbohydrates, sugars, and proteins, and can be used to produce renewable fuel, medical drugs, foods, and cosmetics. Algae are already widely used in food products, from baby formula to ice-cream, providing texture, stabilizing features, and important nutrients for health.

Growing concerns regarding the emission of greenhouse gases have driven investment into algae production as a potential alternative fuel. In addition, the plastics industry has upped its demand for algae to produce biodegradable plastics. According to Allied Markets Research, the global algae products market is expected to generate $3.5 billion by 2025 with growth driven primarily by increased demand for protein based nutritional additives for healthy foods.

Similar to the challenges facing greenhouse food and flower growers that are reliant on the sun, artificial lighting is utilized in algaculture as a supplement to control harvest cycle time and product consistency. Historically, lighting technologies used in algae production were high pressure sodium, metal halide, and fluorescents. Drawbacks of these legacy technologies are the inability to control spectrum and intensity, energy inefficiency, and hazardous chemicals that could contaminate the algae. Recent developments in LED technology have made them the preferred lighting solution in many commercial operations. LEDs offer light output spectrum that can be optimized for penetration through water and photosynthesis, as well as being safer (no harmful chemicals) and more energy efficient. While the "best" spectrum of light is somewhat dependent on the specific algae being targeted, there are general principles that hold true. Like land-based plants, algae strongly absorb and process chlorophyll a & b (red & blue light). Absorption spectra of a few algae are shown in the graph on the right.



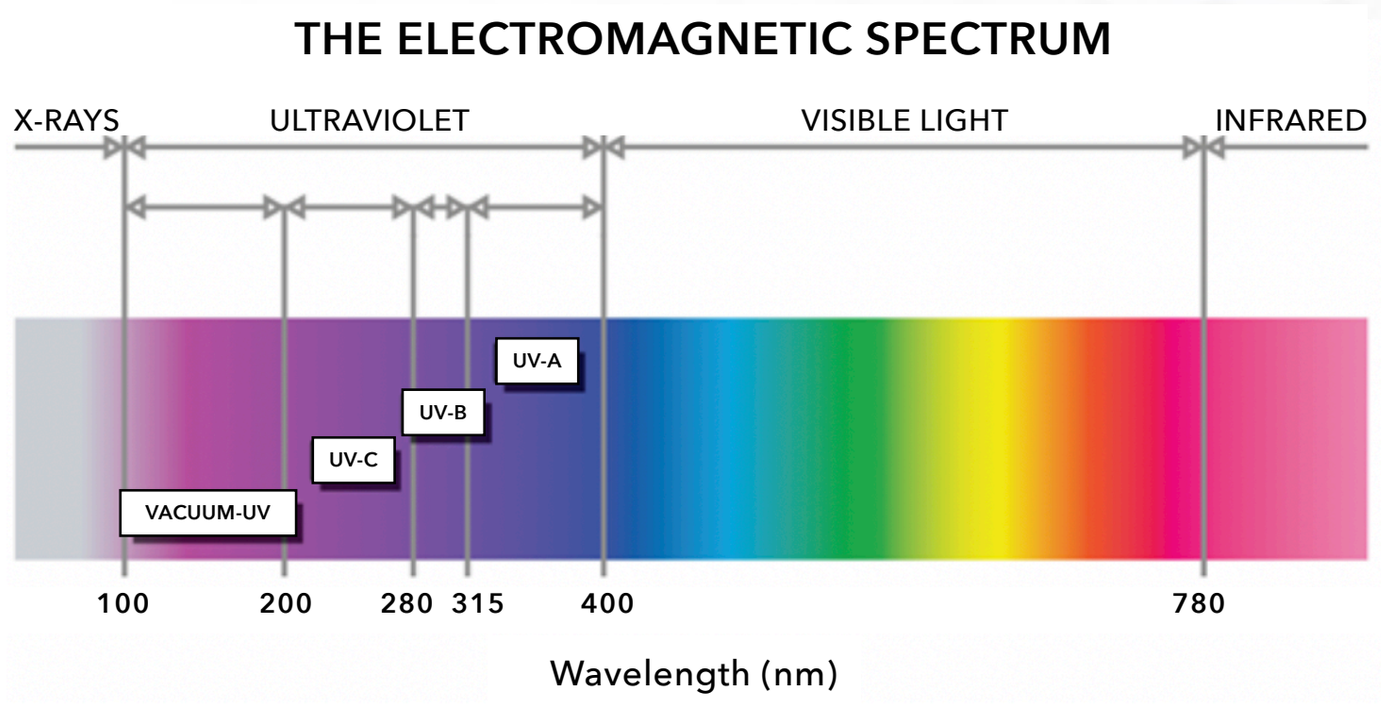
Algae are typically submerged, so the light will need to traverse through some length of water before reaching its target. From the graph, red light is quickly absorbed by water. Blue light is more readily absorbed if the water contains an average amount of organic material. Through a long path of water, green light has the highest transmission. Taking into consideration algae absorption and water transmission, many algaculture farmers choose a full white light spectrum. Other considerations in choosing a light include water/dust resistance, commonly referred to as ingress protection (IP rating). If the lights are to be completely submerged or operated outdoors, they should have an IP68 rating (dust tight and waterproof). Frequently, a separate enclosure is constructed in which the lights are placed since there is a very limited selection of IP68 rated lights.



Thrive Agritech has delivered its LED lighting products to leading microalgae producer, NFusion Technologies, headquartered in Phoenix, Arizona. NFusion purchased the lights due to their optimized full white light photosynthetic spectrum, ease of installation and IP66 rating. Thrive's lights grow algae to be used as organic soil fertilizer for healthier and more sustainable modern farming.

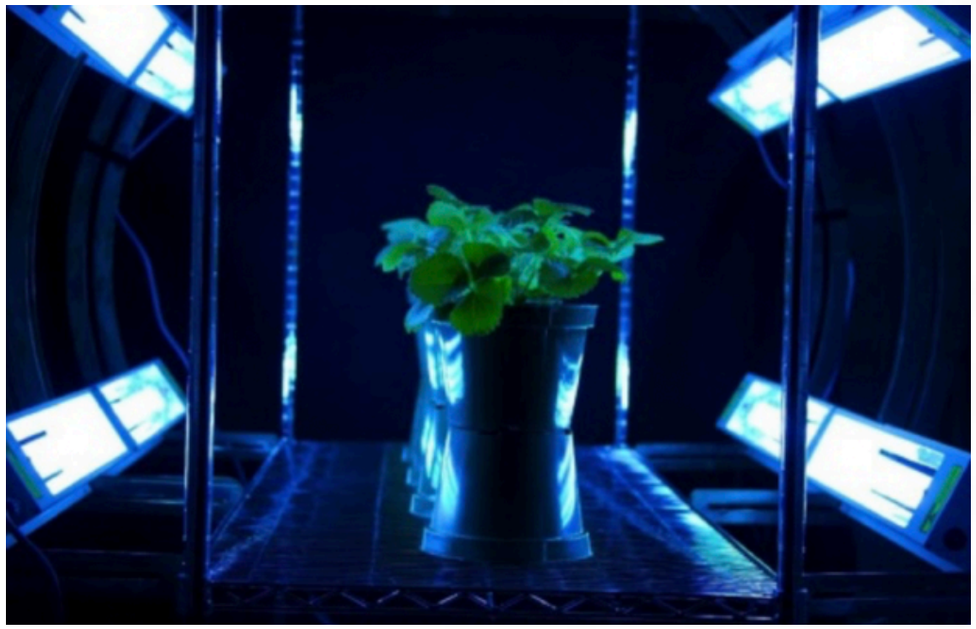
UV LIGHT FOR HORTICULTURE

Although still a niche within controlled environment agriculture, ultraviolet (UV) light has been successfully implemented by some growers to improve crop outcomes. But first, some definitions. Lighting experts frequently talk about the different wavelengths of UV light (UV-A, UV-B, UV-C), so it is important to understand the differences. From the figure, UV light is found below the visible light spectrum and spans wavelengths ranging from 100 nanometers (nm) to 400 nm. UV-A is defined from 315-400nm, UV-B is 280-315nm, and UV-C is 200-280nm. UVA is most abundant in our environment from the sun, as UV-B is partially absorbed by the atmosphere, and UV-C is entirely absorbed. In a greenhouse, much of the natural UV-A and UV-B light is absorbed by the glass.



Benefits of irradiating plants with UV energy include elimination of pathogens and other organisms, and extension of produce shelf life. Further, UV light can create a stress response that causes the plant to make more protective antioxidants to ward off disease and can result in enhanced flavor, texture, and color. For example, the stress response in strawberries has been shown to create more vibrate colors and flavors. And within the rapidly expanding cannabis industry, UV light is being used as a stressor to affect various properties such as THC and terpene levels that deliver stronger plants with more medicinal value.

So which UV wavelengths work best for horticulture? UV-A and UV-B are typically used to impact plant morphology, taste, color, and medicinal properties, while UV-C is primarily used as a disinfectant and in disease control - including powdery mildew. Short wavelength UV-B has also shown efficacy in combating powdery mildew. Research shows that UV-B tends to have the highest efficacy in affecting plant growth. This is because the UV-B waveband is well-aligned to the UVR8 photoreceptor in plants, which induces the stress reaction and mediates photomorphogenic responses. However, UV-B light sources are typically far more expensive than UV-A lights.



UV on Strawberries

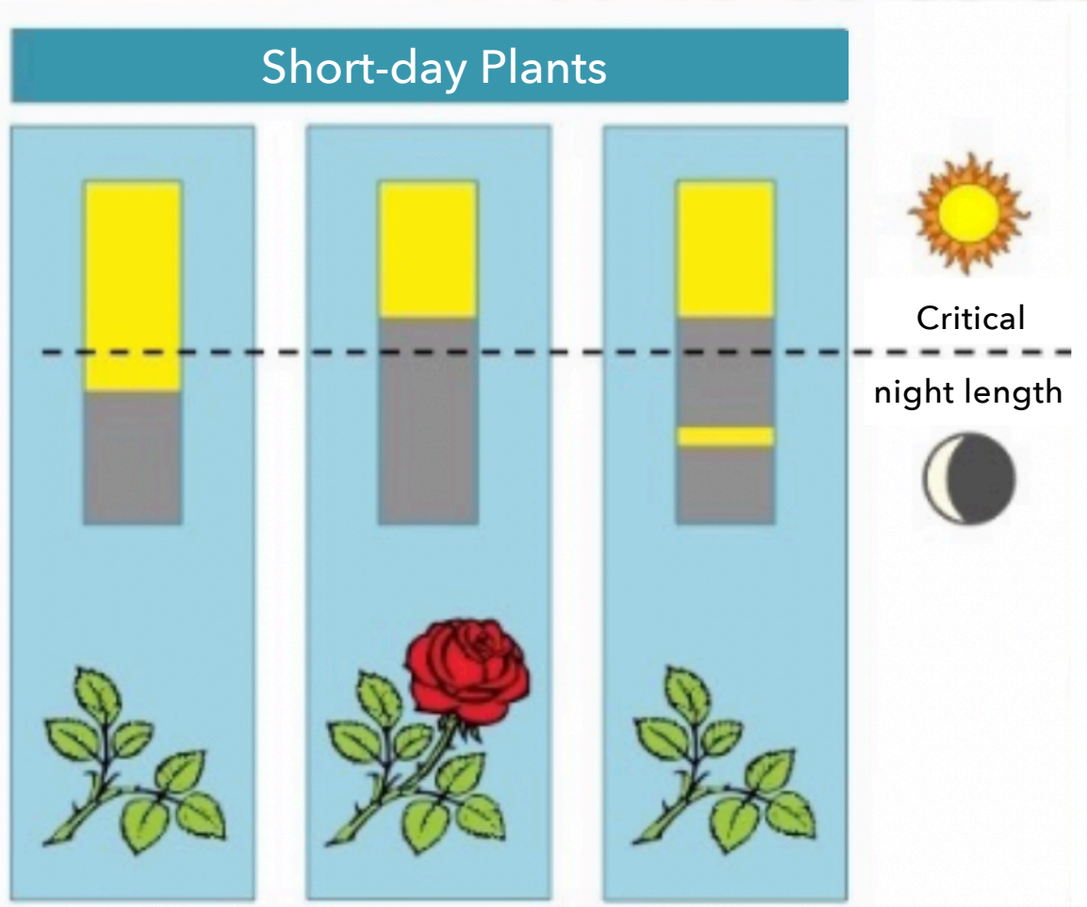
Traditional horticulture lights produce very little UV energy. The amount of UV is about 1% for fluorescent, 3% for metal halide, and 6% for mercury vapor lamps, while high-pressure sodium lamps emit a negligible amount. Recent advances in LED technology have seen the emergence of lighting products with targeted UV wavelengths ranging from UV-A through UV-C. Products toward the UV-A end of the spectrum are significantly more affordable than those in the short wavelength UV-C.

Growers must take care when working with UV lighting. UV light can cause skin cancer and temporary or permanent eye damage. In general, the shorter the wavelength (UV-C is the shortest), the higher the energy content, and the more dangerous to humans.

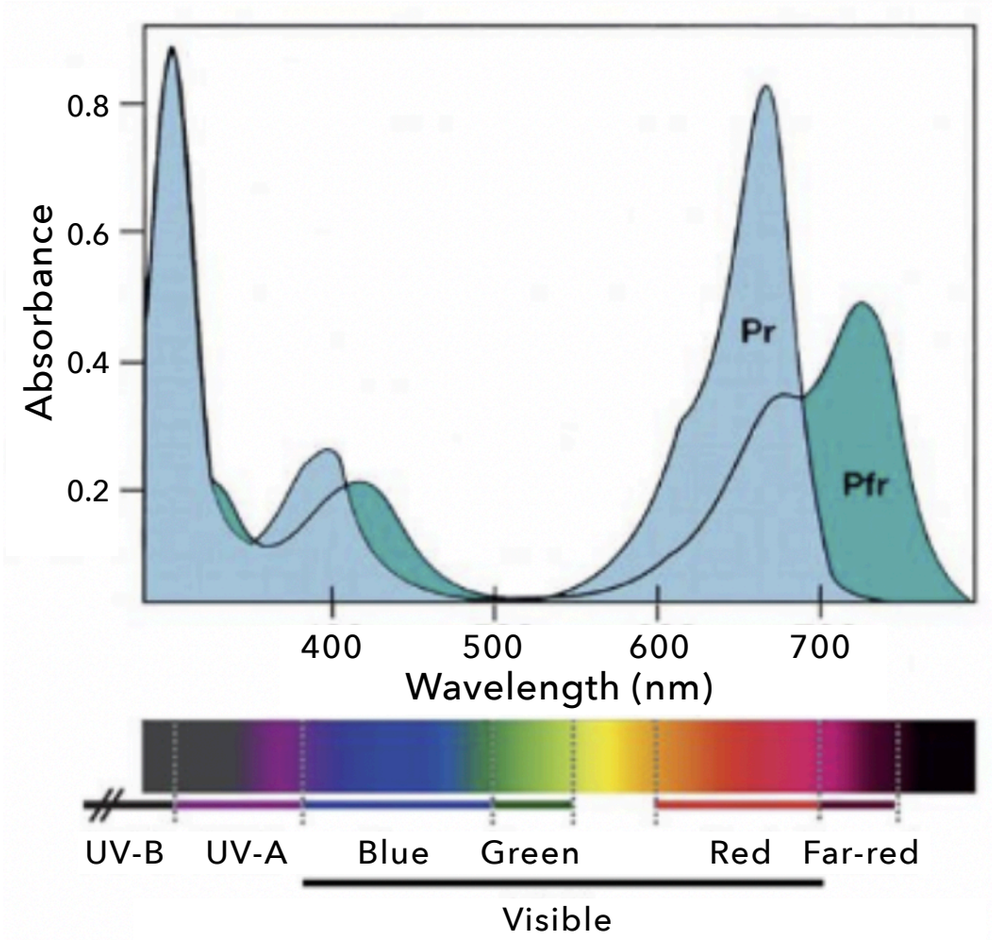
GREEN LED LIGHT FOR CANNABIS OPERATIONS

A flowering female cannabis plant is a necessary condition to produce buds that contain high levels of THC and CBD. So, growers must be skilled at managing the plant's vegetative and flowering phases to maximize production yield. With many plant species, including cannabis, the onset of flowering happens in response to the lengths of light or dark periods. This effect is known as photoperiodism. The biological mechanism of flowering is triggered by phytochromes (leaf pigments), which are used by the plant to detect periods of light and darkness. Photoperiodic plants are classified as either short-day or long-day plants. Short-day plants are those that only flower, or flower more rapidly, when the daylength is shorter than a particular duration. In contrast, long-day plants are those that only flower, or flower more rapidly, when the photoperiod is longer than a critical duration. Cannabis is a short-day plant, so it requires a night cycle long enough to induce flowering. In nature, cannabis plants will flower as autumn approaches and the end of the growing season nears. The plant's phytochromes sense the decreased hours of sunlight, and this initiates the plant's reproductive cycle (flowering) to ensure the next generation.

Much of the cannabis harvested in North America today is grown in the presence of electric light – either as the primary light source in warehouses or supplemental lighting in greenhouses. So instead of being subjected to the light cycles of the seasons, growers can control light and dark periods. In greenhouses, dark periods can be created with shade cloth. Growers typical illuminate plants in the growth/ vegetative phase with about 18 hours of light each day. When they want to initiate flowering, they reduce the light cycle to about 12 hours. One problem growers encounter is how to work in a grow room during the night cycle – when the lights are off. Plants are quite sensitive to broadband (white) light. Even low illumination levels that allow workers to perform their tasks in a grow room will interrupt the night cycle and inhibit flowering (see chart). To solve this problem, growers typically use green light. But why green?



Short-day plants flower when a period of darkness (uninterrupted) *exceeds* a critical night length.

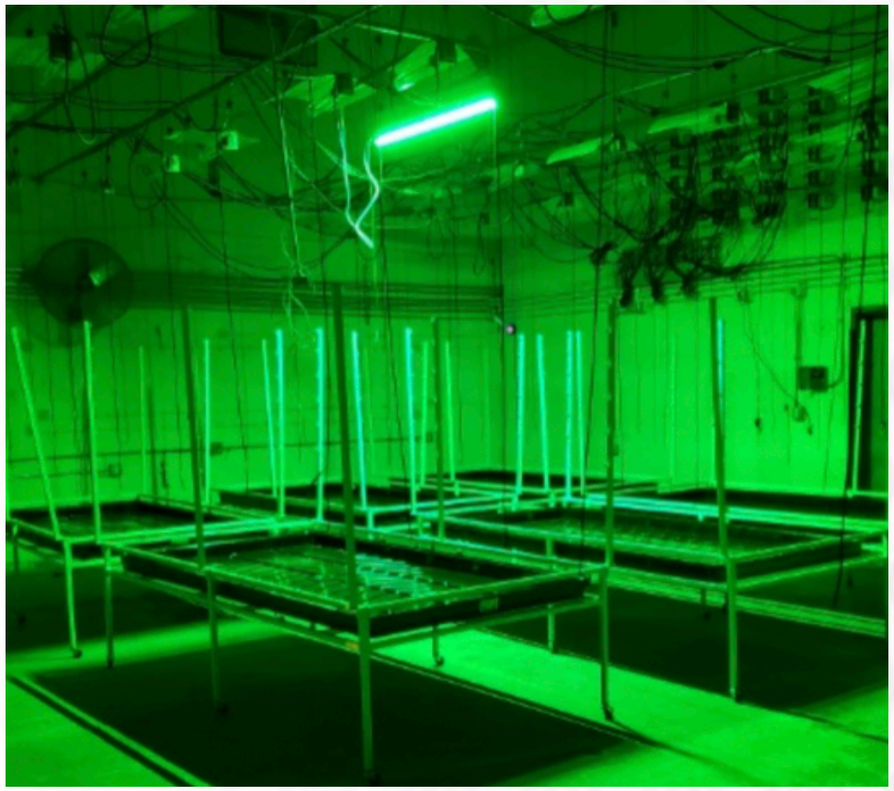


As mentioned, plant phytochromes initiate flowering. Phytochrome molecules are particularly sensitive to red light at about 660nm, and it is the red light that begins the biological chain-reaction within the plant that ultimately leads to flowering. In addition to red sensitivity, phytochromes exhibit other signaling mechanisms (unrelated to flowering) in the blue spectrum. However, there is virtually no phytochrome sensitivity to green light (see phytochrome absorption spectra). So, using green light is a safe way to work in a grow room without interrupting the night cycle.

Commercial green lights come in a variety of form factors and technologies ranging from head lights to fluorescent T5s to LED light bars. Headlights can be cumbersome, and most large cannabis producers prefer to install green lights at fixed locations within the grow room that can be turned on or off as needed.

Fluorescent T5s use optical filters to remove the blue and red parts of the spectrum (leaving only the green). While this works, the result is an energy inefficient solution with limited reliability and product lifetime. Thrive Agritech offers a green LED light bar, called the Verdant light, for commercial cannabis growers that allows workers to tend to their plants during dark periods. Native Roots, one of the leading commercial cannabis growers in Denver, Colorado, has successfully implemented the Verdant light in its grow rooms. Jason MacDonald, Director of Cultivation at Native Roots, comments, "The Verdant Green Light is fantastic for use during the dark cycle, far superior to the green head lamps we were using prior for our sprays and dark cycle harvests. It has drastically improved employee safety and efficiency at our facility."

Verdant LED Work Light



GOOD MANUFACTURING PROCESSES (GMP) AND LED LIGHTING

As quality assurance becomes increasingly important within the controlled environment agriculture (CEA) industry, and within the medicinal cannabis market in particular, there is a proliferation of growers instituting good manufacturing processes (GMP). GMP, advocated by the US Food and Drug Administration, is a system for ensuring that products are consistently produced and controlled according to quality standards. These regulations require that manufacturers, processors, and packagers of drugs, medical devices, some food and blood, take proactive measures to ensure that their products are safe and effective. GMP covers all aspects of production from raw materials, facilities and equipment, to the training and personal hygiene of staff. Detailed written procedures are essential for each process that could affect the quality of the finished product. There must be systems in place that to prove that procedures are consistently followed at each step in the manufacturing process to ensure quality standards. GMP regulations require a quality approach to manufacturing, enabling companies to minimize or eliminate instances of contamination, mix-ups, and errors. This protects the consumer from purchasing a product which is not effective or potentially dangerous.

In greenhouses that uses electric light to supplement the sun to promote photosynthesis, or in warehouses where electric light is used as the primary source, the lights are almost always located directly over the plants. For growers that want to conform to GMP, the lights are considered a critical part of the production equipment and are therefore governed by GMP quality standards. To conform to GMP standards, growers should ensure the lights achieve the following attributes – at a minimum:

- No crevices that can easily collect dust or pathogens that could contaminate the product
- Light output must not decay quickly, thereby affecting production yields
- Wavelength distribution must be consistent over time
- Can withstand sterilization by various chemicals
- Should not be made from materials prone to releasing particles
- High quality equipment that is not prone to malfunctions
- Easy cleaning as well as visual inspection for potential problem areas

Most traditional lighting technologies struggle to meet GMP requirements due to the presence of toxic chemicals – including high pressure sodium (HPS), ceramic metal halide (CMH) and fluorescent. In addition, light intensity and spectral output of these older technologies vary significantly as they age. In contrast, most LED grow lights do not contain toxic chemicals. And the light intensity and spectral consistency over time from LEDs is far superior. But not all LED grow lights are created equally. Growers should ensure the LED product they choose is listed on the Design Lights Consortium (DLC) qualified product list (QPL). DLC listing ensures the LED light meets a threshold for performance, quality, and safety. But even some DLC listed LED lights fail to meet GMP requirements because they have cooling fans that are not covered. And many LED products have heat sink fins that are collection areas for dirt, debris and pathogens.

Fortunately, there are LED grow light products that meet all GMP standards. PharmOut Pty Ltd., a leading GMP consultant located in Melbourne Australia, has recommended Thrive Agritech's Boost LED light to its customers seeking a quality grow light that conforms to GMP. According to Trevor Schoerie, Managing Director at PharmOut, "Whilst the business case for LED lighting is compelling, so is GMP compliance. I love the lights from Thrive due to the well-engineered sanitary finish, easily cleanable, no fins, no external drivers, and reduced wiring, so there are no cracks, crevices or gaps for pests to hide out. If anyone is looking to meet the GMP standards, in my opinion there is only one choice."

Boost LED Light

HYBRID LIGHTING STRATEGIES

LEDs have several advantages when compared against traditional lighting technologies, albeit with higher up-front cost. Benefits of LEDs include energy efficiency, long life and tunable spectrum. Controlled environment agriculture (CEA) facilities are using LEDs where fluorescent and ceramic metal halide (CMH) formerly dominated. High pressure sodium (HPS) lights maintain a substantial share in greenhouses and other very high intensity applications such as cannabis flower rooms. For growers that want to experience some of the benefits of LEDs but have limited budgets, a hybrid lighting solution can be an effective compromise. In the photo (right), we see an example of a hybrid lighting solution. This warehouse installation uses LED lights in conjunction with HPS lights. With this approach overall energy usage is reduced without sacrificing light intensity on the plants. And the up-front cost of the lights is reduced by using HPS to account for about half the needed photons. Further, LEDs allow the grower to easily adjust light spectrum and intensity to influence plant morphology and secondary metabolites.

Greenhouses (photo left) present unique opportunities to leverage the advantages of a hybrid lighting solution. Because LEDs are so efficient, there is little heat in the beam of light that reaches the plants. However, greenhouse growers use the radiant heat from HPS lights to increase leaf surface temperature, which can enhance photosynthesis and ultimately crop yield. The heat from HPS lights are typically needed most during the coldest winter months when the days are the shortest. With a hybrid lighting strategy, growers can use LEDs only when a modest amount of supplemental light is required (during late autumn or early spring). During the darkest and coldest months, growers add the HPS lights that provide additional DLI (daily light integral) to the crop while also providing a boost to leaf temperature.

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