

LED Spectra in Plant Growth

This paper summarizes how LED spectra affect plant growth and health. It provides a generalist summary, as much of the research used is still active, ongoing, and sometimes contested/debated, in particular:

- Many plants have incredibly complex light responses (e.g., some plants may respond differently under blue and green light than under blue light alone).
- Specific ways key pigments, like different types of chlorophyll, respond are still studied (e.g., the measured absorption curves of chlorophyll can vary slightly according to source).
- Performance is highly species-dependent.

This paper lists possible uses for different kinds of light, but you should keep the above caveats in mind.

Which Spectra?

The following is a list of significant spectra peaks and their uses:

COLOR	PEAK	USE
UVC	265nm	Decontaminate, Destroy, Disinfect
UVB	280nm	Mildew Control/Immune system
UVA	380nm	Nutrition/Immune System/Morphology
Violet	420nm	Chlorophyll A Peak
Blue	450nm	Chlorophyll B Peak/Cryptochrome/Phototropin
Green	520nm	Shade Avoidance/Human Interaction
Orange	620nm	Chlorophyll B Peak
Deep Red	660nm	Chlorophyll A Peak/Phytochrome/Flowering/Shade Avoidance
Far-Red	735nm	Phytochrome/Night Treatment/Flowering/Shade Avoidance

When in doubt about which LED colors to choose, it's good to start by including at least 450nm (blue) and 660nm (red) in your spectrum.

Decontamination – 265nm

In general, the shorter the wavelength, the more destructive it is. UVC is limited in its applications but is usually confined to killing off spores and species and keeping certain areas (e.g., air/water supply or returns) decontaminated or isolated.

Immune System – 280nm

Knowledge of UVB light use is limited due to the cost of UVB sources and the difficulty of maintaining them. Recent research suggests that 280nm can induce a response in the UVR8 protein, which can cause some species to seek shade to avoid UV damage.

However, a more straightforward and pragmatic use of UVB is to help control specific pathogens on plants (e.g., powdery mildew).

Nutrition/Pigmentation – 380nm

UVA can induce many of the same responses as 280nm light but to a lesser extent. This is advantageous given that UVB light can be more dangerous to people working under it. Although the intensity needs to be higher to induce the same effect, a lot of the anti-fungal response of UVB is not present with UVA.

For many growing applications, it's important to consider that several UV bands may cause various plants to develop thicker leaf cuticles as protection. This can significantly change the taste of a given cultivar.

Further, some plant species (e.g., solanaceous crops) develop callus intumescence in dim or UV-less light.

Therefore, UVA light may be introduced to avoid physiological disorders or correct a plant's taste and nutrition.

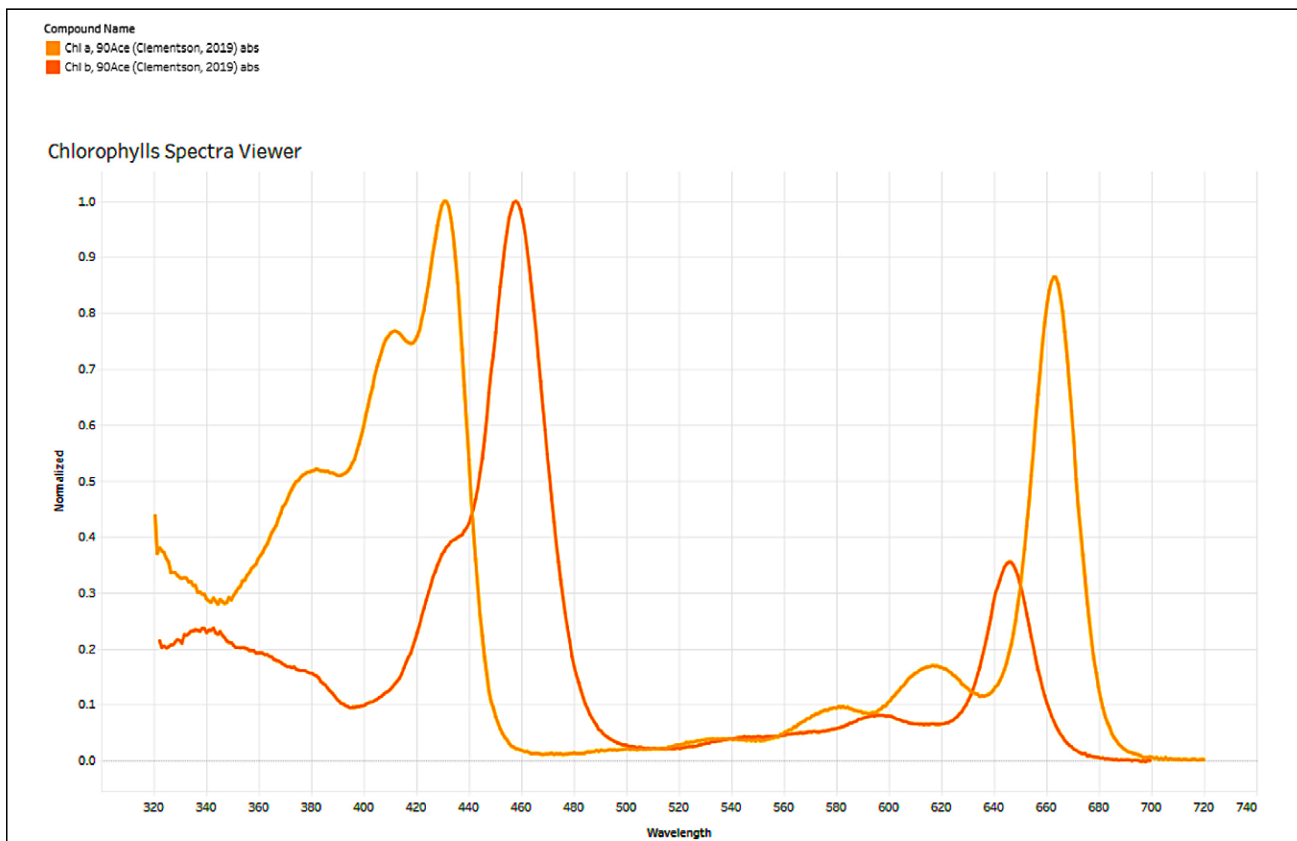
Cryptochrome/Phototropin – 420, 450nm

Two important photoreceptors that absorb 420 and 450 nm wavelengths are cryptochrome and phototropin. Although it is difficult to attribute to one receptor entirely, many stem extension/elongation and leaf size responses in plants have been thought to be due to these receptors.

More importantly, they influence the circadian rhythm of many plants, indicating to the plant whether it is day or night. This includes stomatal responses and can change resulting plant transpiration rates.

Chlorophyll – 420, 450, 620, and 660nm

Because chlorophyll is responsible for a plant's energy, its absorption peaks are the most critical. Let's look at the absorption peaks of chlorophyll A and B:



(Additional Credit: PhotoChemCAD)

There is a significant peak at ~450nm for chlorophyll B and another major peak at ~660nm for chlorophyll A. For this reason, many LED systems include a blue and red LED chip, each optimized at 450nm and 660nm for these absorptance peaks of chlorophyll A and B. By far, these are the most important for general plant growth. In some systems and studies, however, this might be supplemented with 420nm violet, which is another major peak of chlorophyll A, and 620nm red, which is more of a minor peak.

These peaks can also cause significantly different phylogenetic responses (visual appearances) in growing plants. Again, the response is species-specific, but blue light generally causes stem elongation and leaf expansion. Red light can also promote stem elongation and leaf expansion while supporting biomass accumulation and other light-mediated plant responses (flowering, dormancy, seed germination, etc.).

Although not always true, some colloquial sources have possibly over-simplified this to:

- Blue = Out
- Red = Up

Shade Avoidance/Human Interaction – 520, 735nm

Specific bands of light encourage leaf movement, internodal elongation, and “spreading out” instead of “going up” as a strategy to outcompete other plants for light. This response is summarized as “shade avoidance.” Sometimes, shade avoidance is desired to induce a thicker, fuller canopy. While green lights (520nm) can induce a shade avoidance response, they are typically disregarded due to the weak absorption of that waveband in chlorophyll. Frequently, red and far-red lights (735nm) can similarly induce a shade avoidance response due to the diffraction of longer wavelengths as they pass through higher portions of the light canopy. However, given that far-red light can also induce other photomorphogenic effects (e.g., flowering; see below), sometimes green light may be preferred to induce shade avoidance responses.

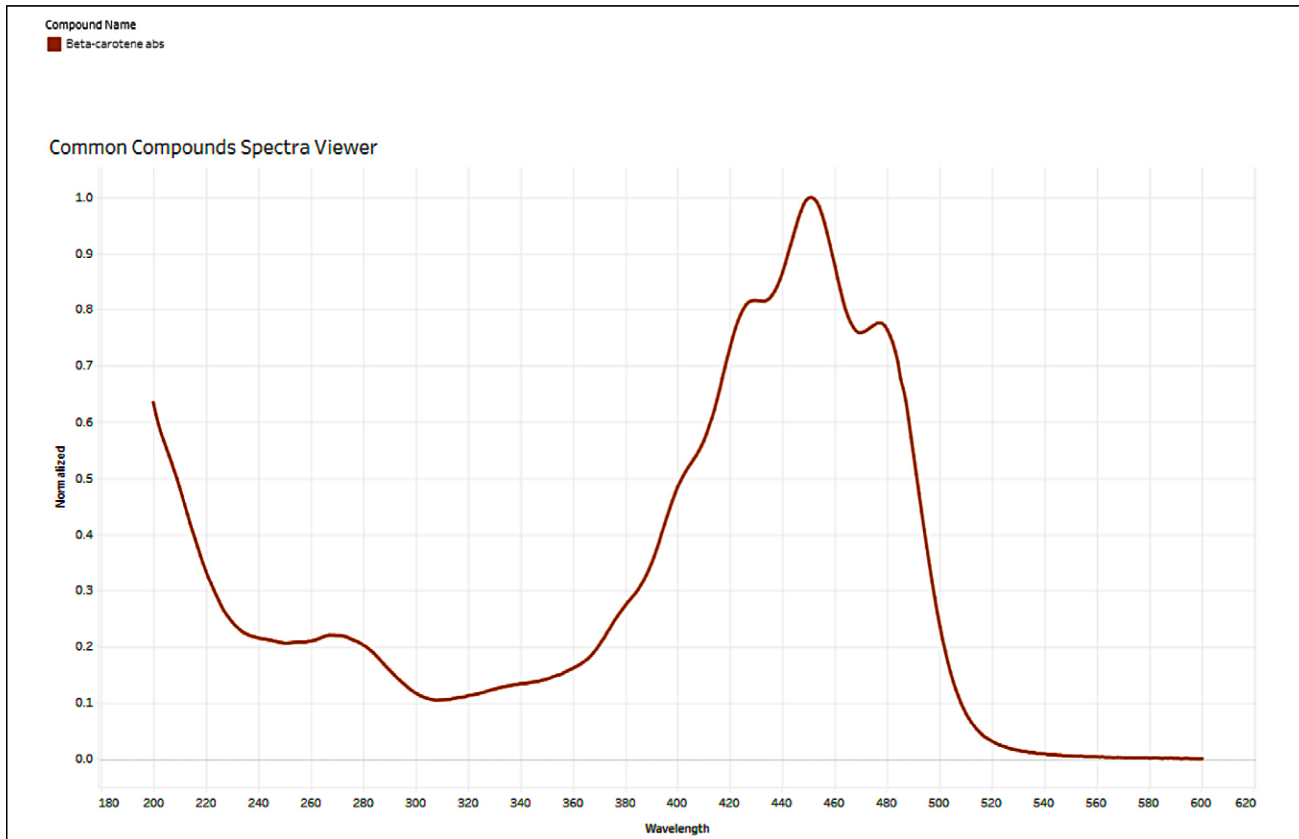
An understated reason for using green light is simply to improve the conditions for human interaction with plants. Because plants reflect little light outside of the green band, it can be challenging to manipulate and inspect plants without green light, and many individuals working with plants have found continued work under the typical purple light to be a significant cause of psychological burnout.

Flowering – 660nm/735nm

Another key pair of pigments outside chlorophyll are the two types of phytochrome: red and far-red. These are suspected to trigger several changes in plants. Because of this, the ratio of red to far-red light can be especially important, as this ratio causes a variety of responses in plants, including morphogenic (stem elongation/expansion) and, of course, flowering.

Other Plant Pigments

Choosing the best spectrum also depends on the species of the plant. A spectrum can affect not just plant performance but often the taste of the plants. When choosing a spectrum, consider that plant pigments can have specific absorption peaks and dependencies. For example, β -carotene (vitamin A, or the orange pigment in carrots) has an absorption spectrum as follows:



When trying to match a particular pigment or chlorophyll type for research purposes, you should keep the absorption peaks of that pigment in mind.

When Should Certain Spectra Be Used?

The best approach for determining which lights to use and when to apply them is to mimic the sun's wavelengths as they occur over a day. Although the effects of this method vary among plant species, this approach is generally the easiest to follow and provides the most benefit.

Due to axial tilt, the sunrise and sunset periods increase the closer one is to the winter solstice. Because of the more extreme angle of the sun during these periods, a higher degree of scattering occurs, leading to a higher proportion of red and, more importantly, far-red light.

Likewise, during the summer solstice, solar noon is more pronounced, and the sun has a longer period where its angle of incidence to the ground is closer to perpendicular, leading to less diffraction, atmospheric absorption, and higher light intensity. This, in turn, means a greater proportion of blue and UV light.

However, don't just consider how things change throughout the season but also throughout the day. For example, some plants benefit from a far-red treatment at the beginning and end of the day. Likewise, increasing blue lights midday can create more effective stomatal responses in plants.

In short, "sync to the sun."

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