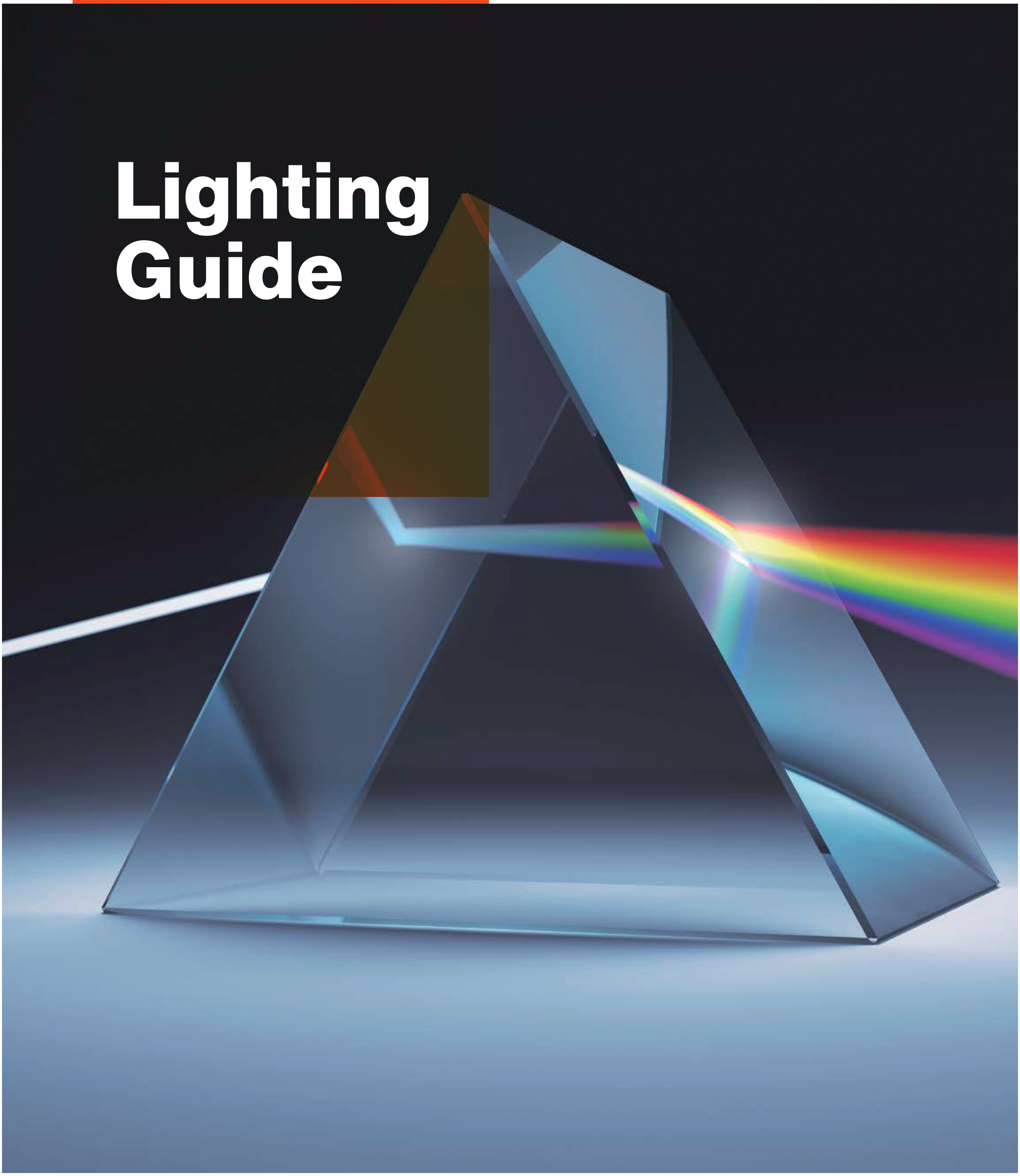
Lighting Guide



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RESEARCH DRIVEN

Defining **Light**

Light is electromagnetic radiation transmitted as photons. In plants light is absorbed by pigments and photoreceptors. Plants use light for photosynthesis in a reaction chain, in which light energy in converted into chemical energy. Light is also conveying information to the plant about its growth environment.

Defining color wavebands is not as straightforward as one might expect it to be. There are ISO standards available, but in plant photobiology ranges commonly used differ from those definitions. For example, according to ISO red is 610-760 nm, but photobiologists may use 620-680 nm according to Sellaro et al. (2010) and in addition, 650-670 and 720-740 nm for calculating red to far-red photon ratio (Smith 1982). (See the definitions table on the next page).

The graph below demonstrates nicely the energy and quantum based properties of the light spectrum. One should be aware of the units used and what is claimed as "sun spectrum". Two standardizations parties commonly referred to, the American Society for Testing and Materials (ASTM) and The International Electrohechnical Commission (IEC) both use the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) program to generate terrestrial reference spectra mainly for photovaltaic system performance evaluation and product comparison. These can also be used as references for other purposes.

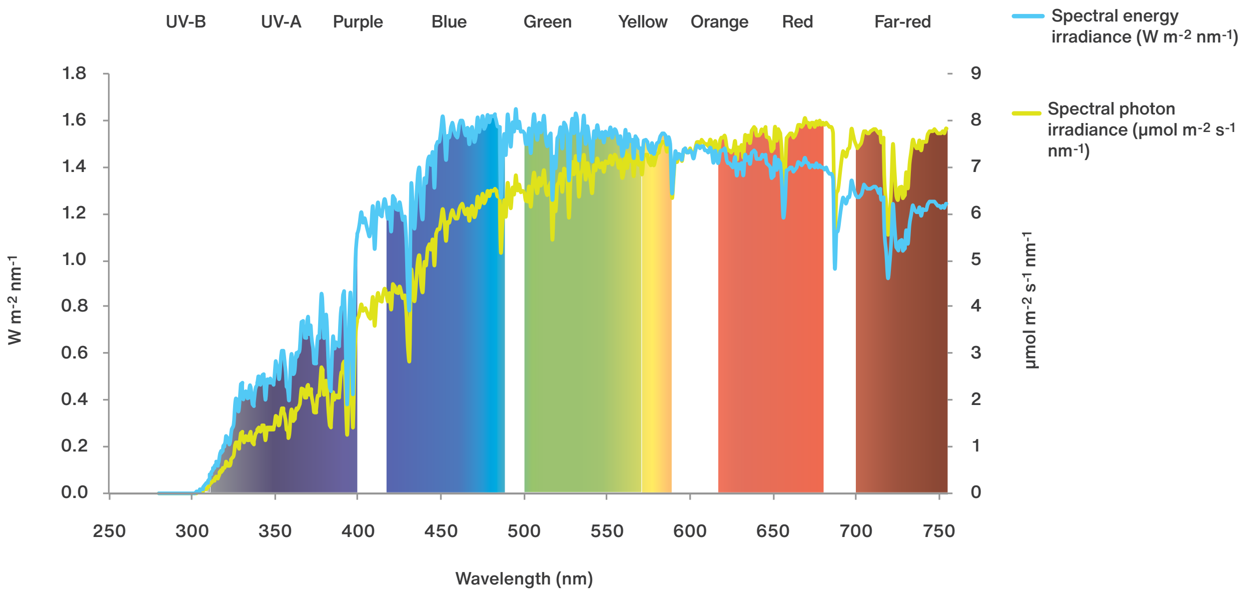


Figure 1. ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2 AM1.5 Terrestrial solar spectrum Air mass 1.5 (AM1.5) (solar zenith angle 48.19 s) from http://rredc.nrel.gov/solar/spectra/am1.5/

Definitions of Light

PBAR

There is critical information for plants beyond PAR area, in the UV range below 400 nm and in the far-red region above 700 nm. These areas and their relative ratios strongly affect plant growth. Hence, it is more accurate to refer to photobiologically active radiation 280-800 nm.

PAR

Photosynthetically active radiation (PAR), designates the wavebands of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. All wavelengths between 400 and 700 nm contribute to the photosynthesis, in addition wavelengths carry information about the plant's surroundings.

R:FR

The R:FR ratio of a spectrum determines the ratio between active phytochromes (Pfr) and inactive phytochromes (Pr). R:FR ratio is the main cue for plants about their environment. Plants grown in shade conditions try to elongate their stem and leaves in order to achieve a better position in the canopy (catch more light), and produce seeds quickly (premature flowering). Sunlight has a R:FR ratio of 1.2 and light under a canopy of leaves has a R:FR ratio closer to 0.1. The lower the R:FR ratio is, the higher is the portion of Pfr of the total phytochromes, thus the stronger the shade avoidance response is. The R:FR photon ratios can be calculated according to the definition by Sellaro et al.(2010); R:FR = (650–670 nm)/(720–740 nm).

B:G and CRY eff. energy radiation

The B:G ratio determines the effectiveness of the blue light responses. The B:G ratio has also been connected to the shade avoidance response (stem and leaf elongation). If the B:G ratio is high, plants have short internodes, stems and leaf petioles. When increasing the green light portion of a spectrum, the blue light responses become "lighter"; plants are not as compact and leaf temperature increases slightly, due to partial stomatal closure. The B:G photon ratios are calculated according to the definitions for different light colours by Sellaro et al. 2010; B:G = (420–490 nm)/(500–570 nm). Cryptochrome activity (CRY2, the blue-light receptor) can be calculated too, when blue light decreases and green light increases the value is smaller.

Pr:Ptot

Ratio between Pr and Ptot (photoequilibrium). Pr:Ptot ratio informs the ratio between the mainly red light absorbing phytochromes (Pr) to all phytochromes (Ptot), measured from a given spectrum (same as PSS value). Pfr absorbs some red light, so in red light, there is a balance of 85% Pfr and 15% Pr. Pr absorbs very little far-red light, so in far-red light, there is a balance of 97% Pr to 3% Pfr.

CCT (Kelvin)

CCT (Kelvin) value is used to describe the color of a light spectrum. Generally the value is only used to describe different colour schemes of white light, i.e. those on a line from reddish/orange via yellow and more or less white to bluish white. Color temperatures over 5000K are called cool colors (bluish white), while lower color temperatures (2700–3000 K) are called warm colors (yellowish white through red). For example, the Valoya ARCH has a CCT value of 3700, and the NS2 4900, and HPS 2100.

CRI

The color rendering index (CRI) is a quantitative measure of the ability of a light source to reveal the colors of various objects in comparison with an ideal or natural light source. CRI can be used to estimate how comfortable the light it is to human eyes, values under 50 are considered to be difficult to work under for long time periods. CRI values for HPS are 20-40, depending on the lamp type. CRI value for traditional red-blue LEDs is zero! CRI values for Valoya spectra vary between 60 to 90, ensuring a comfortable working environment.

Plant Pigments & **Photoreceptors**

Absorption and action spectra

Absorption spectra are measured by spectrophotometer. Action spectra are measured by plotting a response to light as a function of a wavelength.

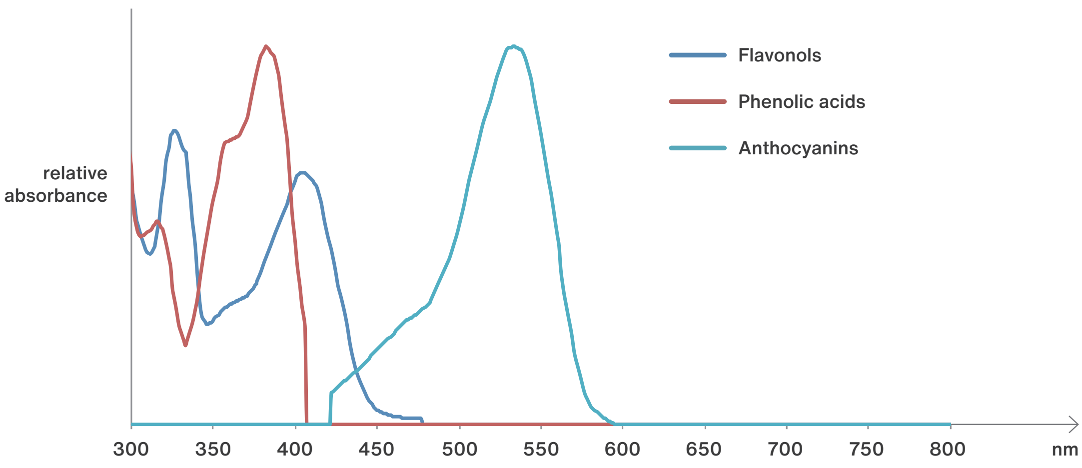
Pigments and phenolics

Chlorophylls (a and b are found in higher plants) are greenish pigments that capture the energy of light. Other pigments associated with the light harvesting machinery of plants, often referred as accessory pigments (e.g. carotenoids, xanthophylls), play an important role in photosynthesis as they increase the range of wavelengths usable for the photosynthetic machinery.

Plants produce a large variety of compounds classified as phenolics. They have multiple roles, serving for example as defence against herbivores, attracting pollinators and acting as "sunscreens", protecting the plant cells by absorbing shorter wavelength light (UV and blue), hence protecting the tissues from high-light stress (photoinhibition). Some phenolic compounds affect also the taste and flavor. Flavonoids are one of the largest group of phenolics; anthocyanins are responsible for most of the colors observed in flowers and fruits and together with flavones and flavonols protect cells from excessive radiation.

Photoreceptors

Plants have the ability to sense small changes in the spectrum, intensity and direction of light. Photoreceptors sense these light signals making it possible for the plant to adjust its development accordingly. Three major groups of photoreceptors have been identified: cryptochromes, phototropins and phytochromes. In addition, UVR8 photoreceptor is involved in the perception of UV-B radiation.



Graph: Relative absorbance of flavonols, phenolic acids and anthocyanins, serving as an example of the large and diverse group of so called secondary metabolites.

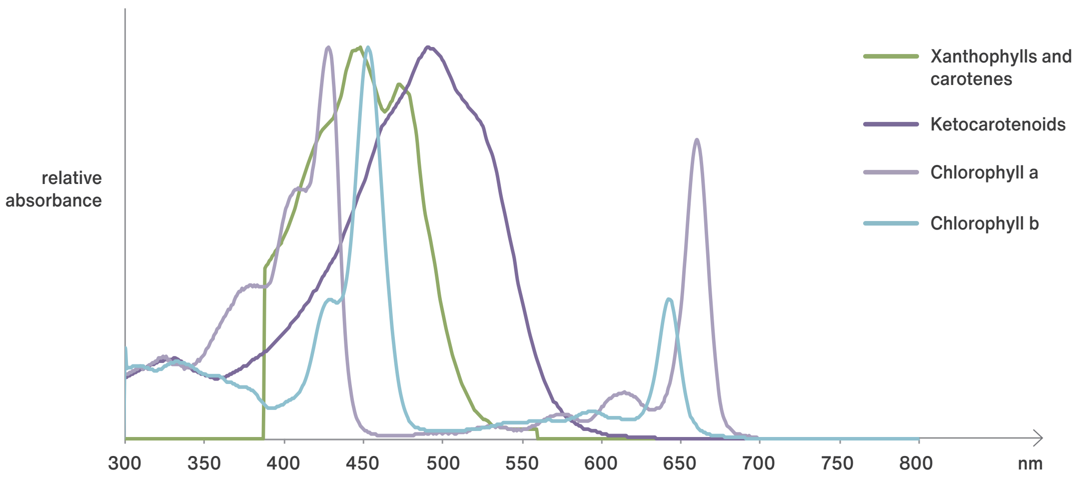
Cryptochromes absorb UV-A, blue, and green wavelengths and are involved in photomorphogenetic responses. Cryptochrome mediated responses are for example cell elongation, stem elongation inhibition, and photoperiodic flowering. Cryptochromes function together with red- and far-red absorbing phytochromes.

Green light can excite phytochromes, cryptochromes and phototropins. Green light has also been shown to be transmitted efficiently and drive photosynthesis in deeper layers of the leaf and enhance growth.

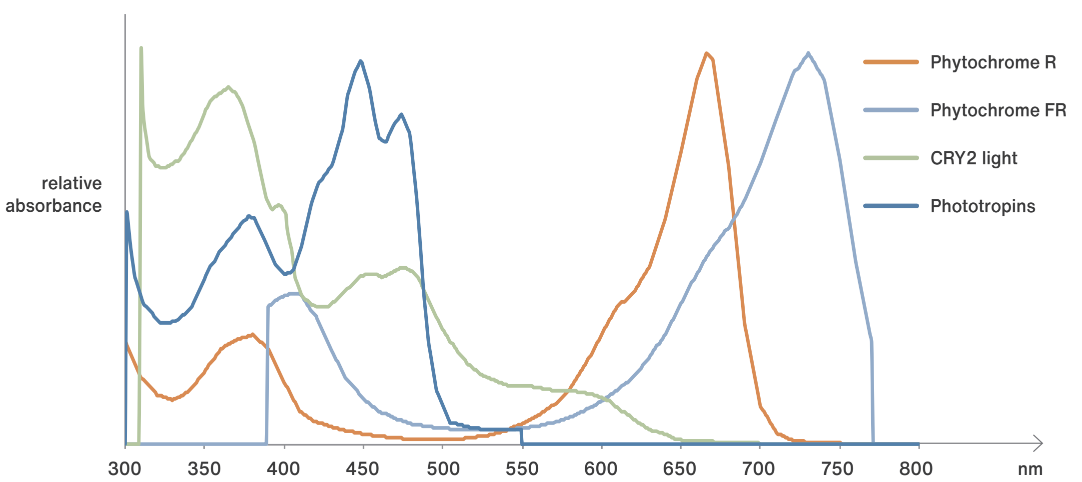
Green light has also been shown to reverse some blue light induced responses.

The variety of different phytochrome responses is extensive. Phytochromes absorb red, blue, far-red, and UV wavebands of the spectrum.

Phytochromes affect stem elongation, leaf expansion and alter plant structure in response to crowding i.e. shade avoidance, which involves the plant perception to the changes in red to far-red ratio. Phytochromes also contribute to flowering.



Graph: Relative absorbance of pigments involved in photosynthesis.



Graph: Relative absorbances of three major groups of photoreceptors.

Using Light to Achieve **Growers Goals**

Photosynthesis

Photosynthesis is about creating chemical energy (assimilates/sugars) from energy provided by light. All wavelengths between 400 and 700 nm contribute to the photosynthesis system, in addition wavelengths carry information that affects plant chemistry and morphology. However, photons at longer wavelengths (far-red) do also contribute to photosynthesis, this so called Emerson enhancement effect was demonstrated in the 1950's. The rate of photosynthesis is greater when both red and far-red light are given together than the sum of the rates when given apart. This provided evidence that there are two photochemical systems working in tandem with a bit different wavelength optima. These are now known as photosystem I and photosystem II. Using the current PAR limits may lead to underestimation of photosynthetic carbon gain.

Photochemical quantum efficiency measures the fraction of absorbed photons that engage in photochemistry, almost all of them do. Energy efficiency then is another thing, since only about a fourth of the energy in each photon is stored, rest is converted to heat. Plants typically convert only 4% to 6% of the available energy in radiation into biomass.

Treating plant responses to elevated CO_2 as an analog to increasing photosynthesis, one can estimate what could be gained through enhanced photosynthesis through plant breeding or genetic manipulation.

Over the daily course, average photosynthetic enhancements under elevated CO_2 are estimated to be about 30%.

However, in studies related to increased levels of CO_2, it has been found that the 30% enhancement in photosynthesis increases relative growth rate by only about 10%.

Increased photosynthesis does not increase relative growth rate at the same speed since enhanced carbohydrate availability can exceed many plants' ability to fully utilize it. This is due to nutrient or inherent internal growth limitations.

Further, focusing only on photosynthesis can give unreliable indications of spectrum performance as the measurements provide results over a short of a time period only, usually only lasting minutes.

The morphology and flowering induction of begonia plants was manipulated by light quality. All plants were grown under same light intensity (PAR 125 µmol/m-1/s-1) in low natural light conditions.

Steering plant growth

Good plant growth is more than photosynthesis. There is critical information for plants in PAR and beyond PAR area, in the UV-B and UV-A range (280-400 nm) and also in the far-red area above 700 nm and in the combinations, e.g. blue to green ratio and especially red to far-red ratio. These areas and rations provide plants with information about its growing environment, e.g. changes in the red to far-red ration enables a plant to detect neighbouring plants and trigger e.g. stem elongation, enabling maximum light capture. Hence, it is more accurate to refer to photobiologically active radiation 800 nm.

One needs to be concerned about the information the light quality provides to the plant and what the plant will do with the resources provided: A leaf, a flower, roots or chemical compounds or the right mix of these all? Will the spectrum aid to produce the desired outcome: What does the grower want to achieve?

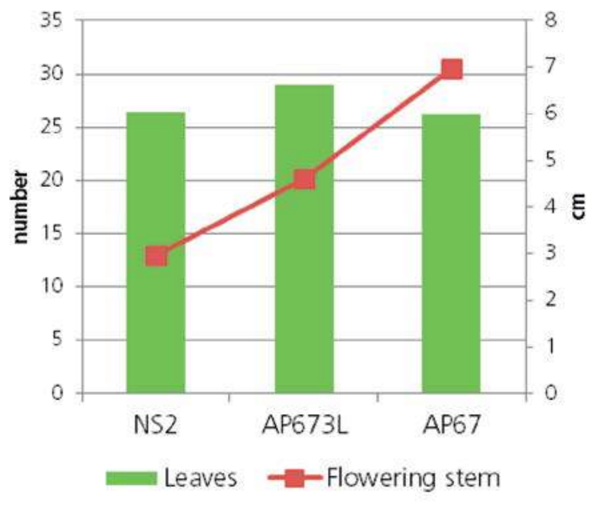
Most horticultural LED providers use off-the-self red, blue, far-red and white LEDs. They claim that red and blue combinations are good for plant growth, just because they happen to coincide on two areas of the chlorophyll absorption curve. They fail to mention that there are pigments other than chlorophyll absorbing the radiation. Without any testing or research, these off-the-shelf LEDs are sold as grow lights, and consequently the customers are left on their own to figure out why their plants are not growing or flowering as expected.

Controlling the light quality and knowing which part of the spectrum and which combinations of the spectrum areas are involved in different processes enables plant growth steering and production of plants with desired characteristics i.e. germination, flower induction, stem, elongation etc. Single peaks of light does not grow plants in the optimal way and energy is wasted on boosting micromoles in the peaks.

Defining a good plant

The performance of the light should not solely be evaluated from an electrical efficiency point of view, but together with the value it provides to the grower. This is rarely only maximum photosynthesis, but the time and cost to get a plant which can be sold (or used) at high value.

Defining a good plant is not about the plant, but about the grower and his business. A good plant to a lettuce producer is one which grows to have high biomass in a short time, looks and tastes good and has a long shelf-life. The lettuce grower does not want to achieve flowering, which should be delayed or even inhibited. For a breeder, a quickly flowering lettuce with high number of seeds is a valuable aspect, thus flowering should be promoted with light quality. For a rose grower a good plant grows quickly to the sellable state, with a big flower and thick stem.



The graph above demonstrates the case with green batavia lettuce. With different Valoya spectra plants can be directed either to flower (AP67), enhance vegetative growth (AP673L) or delay flowering induction (NS2).

Spectra and **Performance**

Spectra designed for purpose

To provide maximum value to its customer, Valoya has developed a variety of light spectra, which enable growers to reach their goals in a highly energy efficient way. Valoya spectra are based on extensive academic, in-house and customer on-site research and then verified by hundreds of professional growers, breeders and research customers.

Valoya has conducted hundreds of trials with plants during the past 6 years, testing unique light spectra based on our own wide spectrum LEDs.

As a result, Valoya has identified several “light applications”, in which a spectrum and a fixture together are designed to save energy, production time, and increase yield and/or quality of the plants.

Based on Valoya’s own and independent 3rd party tests with Valoya and competing companies products, Valoya’s tailored spectra offer superior yields and results compared to narrow bandwidth red-blue LEDs. Narrow bandwidth red and blue LEDs are sometimes successfully used to keep plant compact and to delay plant growth. Valoya also offers some specialized spectra for compactness.

Performance

Artificial light in horticulture enables better growth through longer photoperiods, when natural light hours are limited, better growth through higher daily light integrals (DLI), when radiation from the sun is low or when there is no sun available. Artificial light is also used to control or inhibit flowering in long/short day treatments.

Traditional light technologies, such as high pressure sodium, metal halide or fluorescent, have been basic and simple, offering limited variation of light spectra.

Today, the LED technology offers new possibilities with spectra modifications in an energy efficient way. LEDs not only save energy, but also enable the use of artificial light in a much versatile way than before. By changing the

::: Pictures:
LED technology enables new production methods; spruce seedlings are grown under a custom spectrum in multiple layers without natural light.

spectrum the plants can be conveyed information about their environment, which drives them to have different strategies on how to use the energy generated through energy photosynthesis.

Traditionally artificial light performance has been measured by looking at how much radiation (μmol/s) the light source provides in the photosynthetically active radiation (PAR) area, 400-700 nm. Efficacy has been measured by measuring how many μmol can be produced by each watt of input.

Generic, narrow-band, red-blue, off-the-shelf LED grow lights are widely available at varying costs, depending upon volume, quality and performance. Blue (450-470 nm), red (660 nm), cool white and sometimes far-red (730 nm) are the most commonly used. They are easy to make and were originally intended for generic applications and not for specific use in horticulture - just as the high pressure sodium bulb was designed for street lighting; not the greenhouses they ended up in.

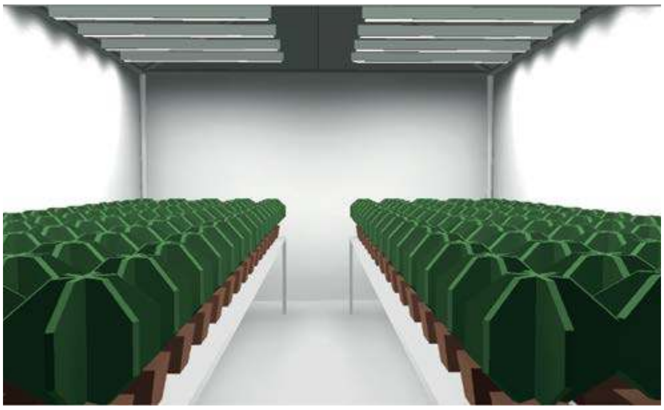
With LEDs, it is very easy to fabricate a pure red (660 nm) spectrum (where all light is within the PAR region) and produce high μmols/W levels with high electrical efficiency. In terms of plant growth, however, there are very few applications where a pure red (or pure blue) light spectrum yields good plant growth results. Therefore, it is vital to develop a suitable technique that includes spectrum quality in the measuring of horticultural light performance.

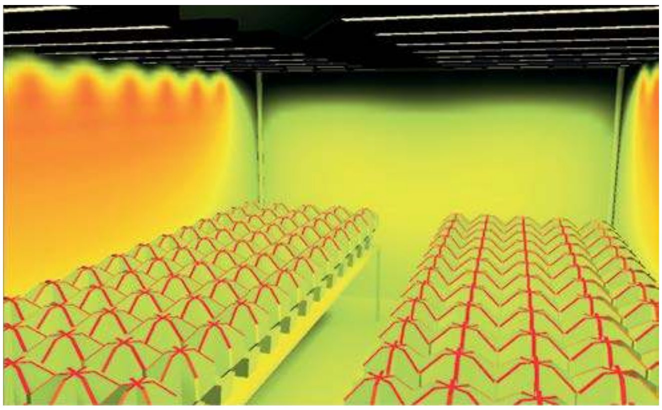
From the LED chip up, Valoya LEDs are made for professional plant growing purposes. This specialization together with the high quality materials and components used, is one factor which impacts cost, i.e. generic grow-lights mainly use cheap generic LEDs and have thus a price advantage when looking only at input wattage.

In the end, what counts is cost of light in relation to growth results and this requires looking at more factors than just price/watt.

A good LED fixture should have the right light spectrum and efficient LEDs. Efficiency of the LEDs should be measured on how much light it provides per watt of electricity input. The best ratio for horticultural purposes is μmol/watt, but it still does not tell anything about the quality of the spectrum and does it promote the desired growth characteristics.

In addition, ensuring uniform light distribution is crucial. Detailed lighting simulations provide information about how many light fixtures are needed for a certain area and how they should be placed, thus ensuring optimal and uniform light distribution. Following pictures show a part of a lighting plan for a growth room with two tables.





Example pictures from a light plan

Cooling, Quality and **Safety**

Heat and Cooling Technology

A high quality LED fixture gives out 30-40% of its energy as light and 60-70% as heat. A fixture with insufficient cooling will give out more than 70% as heat, which contributes to the expense of cooling for the growth environment.

In order to keep LEDs at low enough temperatures to maintain efficiency (high μmol/W), they require constant sufficient cooling. If LEDs are run at too high temperature, it will result in lower efficiencies and cause them to "burn out" quicker.

Cooling can be active, using fans or water, or passive, using a heat sink (often doubling the fixture casing, as in Valoya's case).

Active cooling will enable LEDs to run at a higher current/wattage, lowering costs by using fewer LEDs in the fixture. The downside is the risk of failure to the cooling system. Without regular maintenance, fans can breakdown over time. Neglecting to regularly remove dust and dirt from the fan cooling fixture can lead to overheating and premature failure of the LEDs. High humidity protection and leakage failures have made it very difficult for companies to launch water-cooling technologies into the market.

Taking short cuts in cooling, by under dimensioning the cooling capacity, neglecting or simply using the wrong technology increases the risk of early failure. Yet, if properly designed and maintained, cooling solutions can provide long term use and cost savings.

Quality and Safety

One important factor to check is that the LED provider has all relevant certifications, such as CE markings (and the tests or certifications to prove it), UL or cETLus certifications, to prove they comply with safety regulations. Warranties and decay test results are also an important proof of quality and security for the customer.

Valoya warranty is minimum three years, and the use life is over 35 000 hours (maintaining 90 % of initial light output). As Valoya lights have been used for years, our forecast reaches up to 64 000 hours, while maintaining 90 % of light intensity.

IP rating, humidity and dust protection, are important factors to consider as well. Valoya fixtures are of high IP rating, which is enabled by the passive cooling. Lower humidity rating is of course easier and cheaper to do, but this can restrict their use.

Work space safety, especially concerning eye safety, needs to be verified by standardized protocols. Color rendering index (CRI) can be used to estimate how comfortable the light it is to human eyes, values under 50 are considered to be difficult to work under for long time periods. CRI values for HPS are 20-40, depending on the lamp type. CRI value for traditional red-blue LEDs is zero! CRI values for Valoya spectra vary between 60 to 90, ensuring a comfortable working environment.

References & Further Reading

Further Reading:

Valoya - LEDs Grow Lights. Product Brochure (http://www.valoya.com/brochures)

Valoya - LEDs for Vertical Farming. Solution Guide (http://www.valoya.com/brochures)

Valoya - LEDs for Crop Science. Solution Guide (http://www.valoya.com/brochures)

Valoya - LEDs for Medical Plants. Solution Guide (http://www.valoya.com/brochures)

References:

ASTM G173-03 Reference Spectra. Derived from SMARTS v. 2.9.2 AM1.5 Terrestrial solar spectrum Air mass 1.5 (AM1.5) (solar zenith angle 48.19 s) from http://rredc.nrel.gov/solar/spectra/am1.5/

ISO (2007) Space environment (natural and artificial) - Process for determining solar irradiances. ISO Standard 21348. ISO, Geneva.

ISO/CIE 17166:1999, Erythema reference action spectrum and standard erythema dose.

Sellaro, R., Crepy, M., Trupkin, S. A., Karayekov, E., Buchovsky, A. S., Rossi, C., & Casal, J. J. (2010). Cryptochrome as a sensor of the blue/green ratio of natural radiation in Arabidopsis. Plant physiology, 154(1), 401-409. doi:10.1104/pp.110.160820

Smith, H. (1982). Light quality, photoperception, and plant strategy. Ann. Rev. Plant Physiol. 33:481-518

World Health Organization (WHO) (2002). Global Solar UV Index: A practical Guide.

Notes:

STANDARDS

EUROPE

EN60598-1: Luminaires. General requirements and tests.
EN60598-2-1: Luminaires. Part 2: Particular requirements. Section one – Fixed general purpose luminaires.
EN62031: LED modules for general lighting. Safety specifications.
EN 62493: Assessment of lighting equipment related to human exposure to electromagnetic fields.
EN55015: Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment.
EN61547: Equipment for general lighting purposes. EMC immunity requirements.
EN61000-3-2: Electromagnetic compatibility - Limits - Limits for harmonic current emissions.
EN61000-3-3: Electromagnetic compatibility – Limits - Limits for Voltage Fluctuations and Flicker.
IEC EN 61000-4-2: Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - electrostatic discharge immunity test.
IEC EN 61000-4-3: Electromagnetic compatibility (EMC)- Part 4-3: Testing and measurement techniques - radiated, radio-frequency, electromagnetic field immunity test.
IEC EN 61000-4-4: Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test.
IEC EN 61000-4-5: Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test.
IEC EN 61000-4-6: Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields.
IEC EN 61000-4-8: Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test.
IEC EN 61000-4-11: Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests.
IEC 61347-2-13: Lamp controlgear. Particular requirements for d.c. or a.c. supplied electronic controlgear for LED modules.
IEC 61347-1: Lamp controlgear - Part 1: General and safety requirements.
IEC 62384: DC or AC supplied electronic control gear for LED modules. Performance requirements.
EN62471: Photobiological safety of lamps and lamp systems.
EN62560: Self-ballasted LED-lamps for general lighting services by voltage >50V - Safety specifications.
EN62776: Double-capped LED lamps designed to retrofit linear fluorescent lamps - Safety specifications.

NORTH AMERICA

UL1598: Luminare safety.
UL8750: Light Emitting Diode (LED) equipment for use In lighting products.
UL2108: Standard for Low Voltage Lighting Systems.
CSA C22.2: #9.0: General Requirements for Luminaires.
CSA C22.2: #250.0.8: Safety for Light emitting diode (LED) equipment for lighting applications.
CSA C22.2 No. 250.13-14: Light Emitting Diode (LED) equipment for use in lighting products.

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