Concepcional LED Plant Lighting

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Introduction

• Light means life, growth and joy. But plant lighting also demands energy, so it is generally used in addition to natural daylight to achieve certain daylength or light sums. So far, mainly high pressure sodium lamps are being used, which initially have been developed for street lighting. Their spectrum seems very bright to the human eye, as light is emitted mostly in the middle of the wavelength region (yellow and light red) and the sensitivity of the human eye is highest in this region.

• However, plants have other demands for light quality and use light in a substantially bigger wavelength region for photosynthesis \((\text{PAR} = \text{photosynthetic active radiation} = 400-700 \text{ nm})\). But light is not only energy source for photosynthesis, but also serves as signal transducer for various physiological processes, involving different photoreceptors. Spectral demands of these photoreceptors partly differ considerably from photosynthetically active light spectrum. So one also speaks of photobiologic active light spectrum \((\text{PBAR} = \text{photobiologic active radiation} = 280-880 \text{ nm})\).

• By using latest wideband LED technique, different photoreceptors can specifically be addressed, so morphologic and physiologic processes can be controlled by choosing different light spectrums. Furthermore, light spectrum can be adjusted to developmental stage of plant life.

Effects of different wavelength regions

• UV \((<400 \text{ nm})\) DNA degrading in high doses, in low doses UV-light increases stress tolerance, leads to thick leaves and short internodes. Photoreceptor UV absorbs specifically on UV-A (280-320 nm), further photoreceptors involved are Cryptochromes, Phototropines and ZEITLUPE, but also Phytochromes absorb light in the UV region of the spectrum.

• Blue \((400-500 \text{ nm})\) Stomata opening \((\text{Zeaxanthin, Phototropines})\), hence effective transpiration, low leaf temperature and efficient photosynthesis. Phototropines make sure chloroplasts are adjusted in the right way to incident light, depending on irradiance. Conversion of Cryptochromes, Phototropines and Phytochromes prevents elongation growth and ensures short internodes.

• Green \((500-600 \text{ nm})\) Opposes the effects of blue light, by converting Cryptochromes and Phototropines into their inactive forms. Leads to longer internodes as well as higher leaf temperatures due to partly closure of the stomata \((\text{Zeaxanthin})\).

• Red \((600-700 \text{ nm})\) Especially registered by the Photochrome system. The inactive form of Photochrome is \(\text{P}_{\text{fr}}\) and has an absorption maximum at 660 nm. Radiation in the red region of the spectrum leads to conversion of \(\text{P}_{\text{fr}}\) into its physiologically active form \(\text{P}_{\text{r}}\). The latter is converted back into \(\text{P}_{\text{fr}}\) in Photosensitivity either in darkness (slow reaction), or by exposure to light in the far red region of the spectrum (faster reaction).

• Far Red \((700-800 \text{ nm})\) Opposes the effects of red light by converting the \(\text{P}_{\text{fr}}\) form of Photochrome back into the inactive \(\text{P}_{\text{fr}}\) form (see above). Plants react with so called “shade avoidance symptoms” (= elongated petioles, long internodes, elongated growth, premature flowering).

• Red/Far Red ratio Influences the ratio of inactive Photochrome \(\text{P}_{\text{fr}}\) and active Photochrome \(\text{P}_{\text{r}}\) (see above). Direct Sunlight has a red/far-red ratio of about 1:2. Under a dense canopy however, driven by shading through other plants, the ratio gets as low as 0:1. When exposing plants to radiation with high red/far-red ratio, reactions on red light are predominant (short internodes, compact growth). Conversely, a low red/far-red ratio leads to the so called “shade avoidance symptoms” described above.

• Blue/Green ratio As green light opposes the effects of blue light, the blue/green ratio of a light spectrum provides information about the intensity of the blue light reaction. A high blue/green ratio generally leads to short internodes and leaf petioles; conversely, with increasing the green component of the spectrum, these plant reactions are weakened.

Conclusions

Comparison of spectra and plant reactions

• The mentioned plant reactions on particular wavelength regions have no general validity, as involved photoreceptors, their absorption spectra and triggered reactions can widely differ with plant species.

• A complex network of photoreceptors provides for different morphologic and physiologic plant reactions. For this reason, the prediction of plant reactions on the three used LED spectra (full spectrum, red/far-red and blue/green) is only possible to a very limited extent. Categorization of the spectra in [juvenile] \(\text{Valonia NS1}\), [vegetative] \(\text{Fionia FL300 grow white}\) and [generative] \(\text{Valoya AP67}\) is only a vague classification. So for example the spectrum \(\text{Valonia AP 67}\) can be a quite good choice for vegetative growth, despite its high proportion of flower promoting far red, while the \(\text{Fionia FL300 grow white}\), with its very high red/far red ratio, should be not the best choice for early flower induction in many plant species.

• The widespread distribution of photon flux over a great wavelength range is a common feature of all three used LED spectra. High pressure sodium lamps employ much of the used electric energy in narrow banded peaks in the yellow to light red wavelength region.

Comparison of energy efficiency

• For evaluation of different types of lamps for plant lighting, the unit “lux” which is familiar to many people, is not a good choice, as not brightness of a light source is crucial for plant growth, but its ability to provide energy (in form of photons) for photosynthesis. So for comparison of different lamps for plant lighting, the unit PPFD in the range from 400 to 700 nm \((\text{PPFD} = \text{photosynthetic photon flux density})\) per watt power usage of the lamp, is best suited.

• All measurements have been conducted with a distance of 150 cm between lamp and sensor, which is the actual spacing between lamp and growing table when used in the low energy greenhouse. The high pressure sodium lamp had lowest photon flux density per watt with 0.14 \(\text{mmol m}^{-2} \text{s}^{-1}\), closely followed by Fionia FL300 grow white with 0.15 \(\text{mmol m}^{-2} \text{s}^{-1}\). Much higher values for energy efficiency were achieved by Valoya LEDS \((\text{AP67}: 0.40 \text{ mmol m}^{-2} \text{s}^{-1}, \text{NS1}: 0.52 \text{ mmol m}^{-2} \text{s}^{-1})\).

• These results suggest that plant lighting with latest wideband LEDs could potentially outclass conventional plant lighting with high pressure sodium lamps in terms of energy efficiency. However, to comprehensively evaluate this topic, further investigations are necessary, concerning homogeneity of light distribution and size of illuminated area.

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