APPLICATION NOTE:
SPECTROSCOPY PLAYS A KEY ROLE IN THE FUTURE OF SMART AGRICULTURE

Techniques

Reflectance Spectroscopy

Keywords

- UV/VIS Absorbance
- Horticulture
- NIR Spectroscopy
- Plant Health Monitoring
- Quality Control
- Reflection Spectroscopy

Introduction

Agriculture of the future will be shaped by the forces of climate change and population growth as well as technological advances and many other factors. In the end, however, this means that the farms of the future will need to produce more with less, and often in ever-worsening conditions. The advances that will make the farming of the future possible, are in development today.

Plant Physiology Research

Plant physiology, how plants grow, develop, and reproduce, affects production yield and quality in numerous ways. Light is possibly the most important environmental factor that affects plant physiology. Plants produce diverse responses to the quantity, quality, direction, and duration of light cues in their environment. They produce hormones and other secondary metabolites that affect production yield, food quality, and taste.

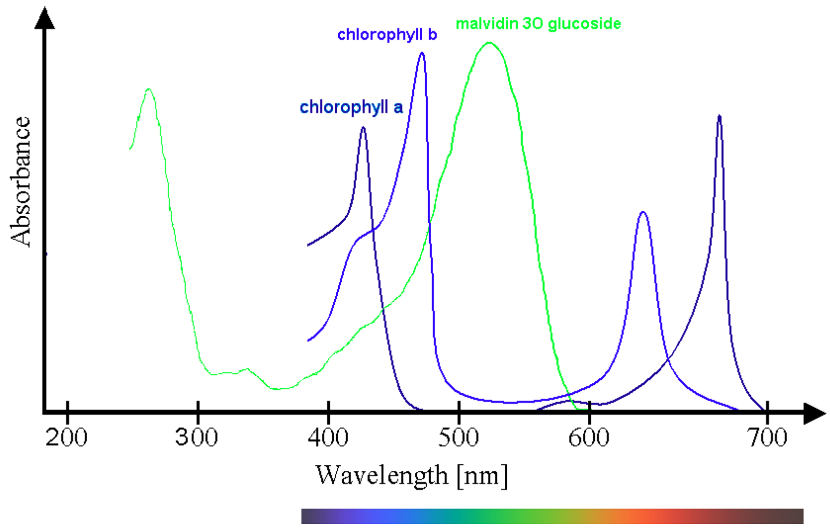
Understanding plant responses to light cues is essential for successful indoor cultivation. Researchers from Denmark, Bulgaria, and Belgium have been studying the effects of differing light conditions on plant physiology. Plants possess photoreceptors that sense ultraviolet-B, ultraviolet-A, red and blue light. These photoreceptors are capable of sensing the intensity, quality, direction, and duration of light.

Red v. Blue Light

The photosynthetic photon flux density (PPFD) represents the number of photons used for photosynthesis within the 400-700 wavelength range of photosynthetically active radiation (PAR). Red and blue light are effectively absorbed close to the surface and are the most important wavelengths for photosynthesis. Chlorophyll, the primary plant pigment responsible for photosynthesis, absorbs both blue (420-450 nm) and red (600-7100 nm) light. Chlorophyll type-a has absorption peaks at 430 nm in the blue range and 665 nm in the red, while chlorophyll-b demonstrates absorption peaks at 453 nm (blue) and 642 nm (red). Light absorption in chlorophyll dips to its lowest at 550 nm. (Ouzounis 2019)

Because it has a higher frequency and therefore shorter wavelength, blue light contains more energy than red light. Photosynthesis, however, is dependent on the total number of photons absorbed, not the energy content of the individual photons. In the case of blue light, the additional energy is lost as heat. This effect is evident in the lower efficiency in the blue range. (Ouzounis 2019)

Different species of plants respond differently to red and blue light, and even different varieties of the same species might thrive best in differing light conditions. Seedling plants sold in containers are frequently grown in crowded conditions with insufficient light and typically have elongated hypocotyl, the stem found below the seed leaves and directly



above the roots, due to poor light quality. This results in plants that are unnaturally tall with thin foliage and low fresh weight yield. This elongated characteristic is particularly pronounced in herbs and spice plants. Dill plants in particular, display very high elongation, fewer leaves and smaller leaf area due to light quality during the germination phase.

Researchers at the Poznan University of Life Sciences, in Poznan Poland studied varying doses of blue light between 10-15% with a constant proportion of red light and the effect on dill plants. They found that in general, dill plants treated with red light were taller overall and displayed elongated internodes whereas the plants treated with blue light had shorter internodes and produced relatively high herb yields. The plant response to blue light, however is very sensitive and depends not only on the proportion of blue or red light, but also the growth stage of the plant. (Frąszczak 2016)

The elongation of the hypocotyl stem structure was most suppressed under high doses of blue light during the very first weeks of germination, with the shortest hypocotyl length displayed by plants grown under 50% blue light. At later stages of growth, however, lower doses of blue light might be sufficient to suppress elongation, while providing benefits to net photosynthetic rate where the highest values were found in plants that were treated with blue light under 30%. (Frąszczak 2016)

Other plant species demonstrate optimal growth under different conditions. For Cherry tomatoes, for example, a 1:1 ratio of red to blue light was found to be effective, whereas a red to blue ratio of 0.9:0.1 may be a better ratio for some lettuce, spinach, and radish. While blue light suppressed stem elongation in dill plants and lettuce, Eggplants grown under blue light display longer stems than plants grown under any other color. Light may modify the expression of non-food commercial plants as well. Increasing the proportion of blue light to roses and chrysanthemums resulted in lower flower heights. (Frąszczak 2016)

Ultraviolet Radiation

Due to depletion of the ozone layer, ultraviolet-B radiation (280-315 nm) has an increasingly negative impact on Earth's living organisms, and other than extremely high altitudes, ultraviolet-C radiation is absorbed in the upper atmosphere and rarely reaches the Earth's surface, except that that may no longer be true. Scientists recorded direct solar UV-C radiation reaching the ground in Madrid in 1997. (Katerova 2009)

Researchers at the Bulgarian Academy of Sciences studied the effect of UV-B and UV-C exposure on three important plant hormones that regulate response to environmental stress, Abscisic acid (ABA), indole-3-acetic acid (IAA), and 1-amino-cyclopropane-a-carboxylic acid (ACC). These phytohormones are involved in regulating developmental processes such as plant growth and lateral root initiation in response to environmental cues. (Katerova 2009)

Spectral Properties of Artificial Light

Greenhouse plants typically supply plants with 16-20 hours of artificial light per day at intensity ranges of 100-200 µmol*m-2* s-1. For years in indoor plant cultivation, the High-pressure Sodium (HPS) bulb has been the industry standard due to their high efficiency (1.9 µmol*m-2*W-1) at turning electricity into photosynthetically active radiation. But light from HPS lamps is still suboptimal, producing light mostly in the yellow and orange ranges with some red light between 550- 650 nm. Only about 5% of the light produced by HPS bulbs is in the blue range, and there is no way to modify their spectral output.

Light Emitting Diodes (LEDs) provide light within a narrow spectrum ranging from ultraviolet to near-infrared allowing manipulation of the light spectrum to trigger physiological changes with potential benefits to plant growth. The light distribution properties for LEDs are comparable or better than their HPS counterparts, making them a fully scalable substitute. LEDs increasingly have comparable quantum efficiency to HPS lamps, and in the cases of some new Dutch and Danish manufactured fixtures (2.2-2.4 µmol* M-2*W-1), may even exceed the capability of HPS lamps. LEDs are also solid state, durable light sources that offer superior bulb life, reaching up to 100,000 hours compared to the average HPS lifespan of 10,000-20,000 hours. (Ouzounis 2019)

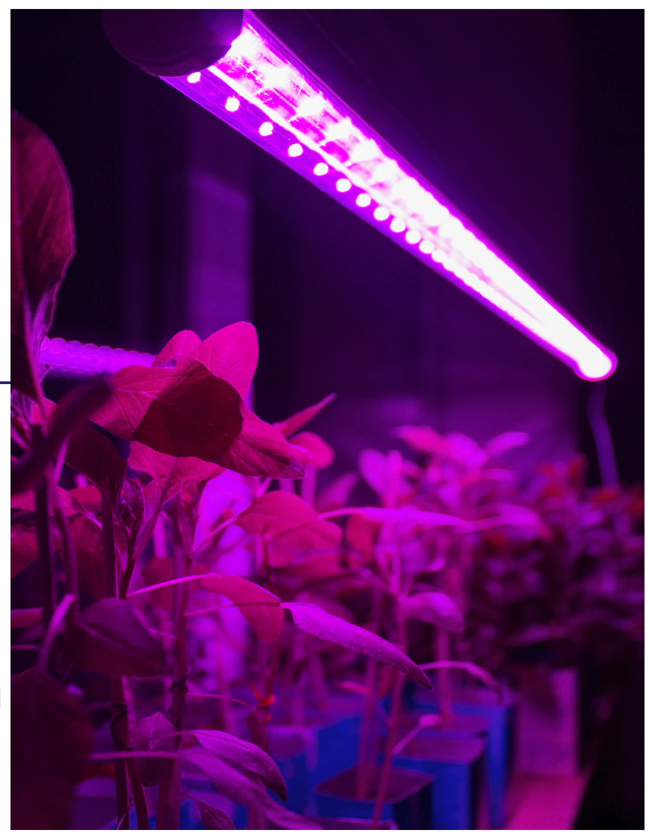
Avantes has been a pioneer in the implementation of spectroscopy within greenhouse environments. Spectrometers from Avantes have been used to optimize LED light mixtures as well as automatically adjust shading system within greenhouses to regulate the daily light integral (DLI) which is the total amount of light received by a plant in a 24-hour period.

Plant Health Monitoring and Quality Assessment

One of the more common areas of interest in Smart Agriculture is achieving a non-invasive means of measuring plant health and quality. Spectroscopic diffuse reflection is ideally suited to this application as it requires limited hardware and can be performed at very high speeds (e.g. 600 spectra per second). A notable example of this technique can be seen in image 1 below which depicts a sensor head mounted on the top of a tractor which is pulling a fertilizer implement. This system which was developed and is commercialized by Yara AG simultaneously measures the solar illumination and correlates this with reflection data from the crops. The reflected light from the crops provides rich information about the chlorophyll content allowing for the derivation of a health score which in turn regulates the fertilizer application level in real time and then maps this to GPS coordinates for future monitoring. This system provides an excellent example of the potential of SMART agriculture to better utilize resources to improve agricultural yields.

Crop quality is another important area of agricultural production where spectroscopic techniques have been successfully implemented. Researchers at the Polytechnic University of Valencia, Spain, are using Avantes instruments in developing a mango quality index for prediction modeling and the development of a robotic gripper capable of simultaneous tactile and NIR spectroscopy measurements to determine mango quality and ripeness. (Cortes 2017)

This non-destructive method of assessing fruit quality is based on biochemical and physical properties of mango samples. Mangoes are typically not ready for consumption at the time of maturity, requiring a period for ripening during which many important chemical and physical changes take place within the fruit. Diffuse reflectance spectroscopy was used with a fiber optic probe in direct contact with the mango skin to measure changes in soluble solids, ascorbic acid, water content, and skin color. An Avantes multichannel spectroscopy system was used in the development of this quality index. The AvaSpec-ULS2048-USB2 Starline spectrometer covered the visible range from 600-100 nm and an AvaSpec-NIR256-1.7 NIRLine spectrometer covered 900-1750 nm.



Spectroscopy for Light Characterization

Spectrometers and spectroradiometers are essential tools for the characterization of natural and artificial light in agriculture. While sometimes confused with a sensor, these devices provide robust information about the quality and quantity of light which is received, absorbed, or transmitted by plants. A sensor, conversely, is typically limited to measuring a narrow band of light wavelengths received in aggregate. Given the importance of the composition of light wavelengths received by plants, spectrometers are valuable tools for characterizing this composition.

Avantes AvaSpec instruments are robust and optimized for the challenges of field spectroscopy. Within the UV/VIS range two of the more common candidate instruments used in this application are the AvaSpec-ULS2048CL-EVO and the AvaSpec-Mini2048CL which are optimal candidates for field use due to their robust yet compact designs, high speed data acquisition and thermal stability. For near infrared applications the AvaSpec-NIR256/512-1.7-EVO and AvaSpec-NIR256/512-1.7-HSC-EVO are the go to instrument for grain and sileage analysis in the field.

For more information about Avantes instruments for agricultural applications, please contact a sales engineer at infousa@avantes.com.

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