A SPECTROSCOPIC SET-UP DEVELOPMENT FOR EFFICIENCY ANALYSIS OF HPS AND LED LIGHTING IN HORTICULTURE

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Abstract

Using efficient light sources are important to obtain the optimal results for plant production. An artificial light source for plant growth must convert as much electrical energy as possible into PAR energy. We developed a customized spectroscopic measurement set-up and spectrometer application to measure the illumination conditions in horticulture. As a pilot project we compared High Pressure Sodium (HPS) grow lighting with LED lighting. We measured the light spectrum, the light intensity of two lamps, and some environmental parameters: the temperature and humidity. Moreover, comparisons were made to the amount of energy used.

Our goal was to show the benefits of the LED lighting and our measurement technique. In advanced LED farming light composition can be controlled to avoid surplus warming. Among others, it means less additional investments, more attractive biotic habitat for insects, such as bees, while energy consumption is reduced and environmental conditions are improved.

Keywords

HPS lighting, LED lighting, spectroscopy

Introduction

Plant production systems can be characterized by their natural and artificial stability, and natural and artificial controllability (control ability) (Table 1). Different plant production systems differing in stability and control ability are needed to maintain the overall sustainability of society under changing climate and social conditions. The plant production system to be chosen depends on its purpose under the given social, environmental, economic, and resource conditions.

Table 1. - Classification of Four Types of Plant Production Systems by Their Relative Stability, Source: Kozai T. (2015)

Stability and Controllability	Open Fields	Greenhouses		Indoor Systems[a]
		Soil Culture	Hydroponics[a]	
Natural stability of aerial zone	Very low	Low	Low	Low
Artificial controllability of aerial zone	Very low	Medium	Medium	Very high
Natural stability of root zone	High	High	Low	Low
Artificial controllability of root zone	Low	Low	High	High
Vulnerability of yield and quality	High	Medium	Relatively low	Low
Initial investment per unit land area	Low	Medium	Relatively high	Extremely high
Yield	Low	Medium	Relatively high	Extremely high

[a]High/low evaluation is valid only when the manager's skills are fairly high.

Indoor plant production systems can be divided into two types in terms of light source: artificial light only and artificial light and (supplemental) solar light. Growers can gain the experience of field crop cultivation once or twice a year under changing weather and climate. As for greenhouse cultivation of fruit vegetables, the experience can be acquired one to four times a year in most cases under a controlled environment, although the cultivation know-how depends on the season and the presence of diseases often caused by pest insects.

In the case of PFAL[1] cultivation of leafy greens or other herbaceous plants, growers can experience seedling production and cultivation of seedlings until harvesting 10–20 times a year under precisely controlled environments. Thus, experience and know-how about PFAL cultivation can be accumulated much faster than for open field and greenhouse cultivation. During PFAL cultivation, growers can conduct a simple experiment by changing only one factor - for example, the light source, cultivar, or nutrient composition; other factors remain unchanged. This enables the growers to understand the cause-effect relationship easily. Also, the results of PFAL experiments are not affected by the weather, so PFAL experiments are more reproducible than open field and greenhouse experiments. PFALs used mostly for commercial production, consisting of the essential components listed in Table 2.

[1] PFAL: Plant factory with artificial lighting

Table 2. - Essential Components of a PFAL Source: Kozai T. (2015)

No.	Essential Component of PFAL
1	Airtight (no. of air exchanges is lower than 0.015 h^{-1})
2	Thermally well-insulated roof and wall (heat transmission coefficient is lower than 0.15 $W/m^2/C$)
3	Air shower or hot water shower at the culture and operation rooms
4	Multitiers with lighting system and hydroponic culture beds
5	Air conditioners mainly for cooling (dehumidification at the same time) and air circulation
6	CO_2 enrichment to keep its concentration at around 1000 ppm
7	Floor covered with epoxy resin sheet for keeping it clean
8	Collection and reuse system of water condensed at cooling panel (evaporator) of air conditioners
9	Circulation and sterilization system for nutrient solution supply

Other indoor plant production systems with artificial lighting only are called "o-PFAL (open-PFAL)" or "m-PFAL (mini- or micro-PFAL)" in this book.

LEDs represent an innovative artificial lighting source for plants, both as supplemental or sole-source lighting, not only owing to their intensity, spectral and energy advances, but also via the possibilities for targeted manipulation of metabolic responses in order to optimize plant productivity and quality. With LED lighting the spectral output can be tuned, which makes it possible to apply the optimum 'light recipe' at every stage of a crop's growth. Research on the effects of LEDs on primary and secondary metabolism of plants and on how the direction and mixing of LEDs influence plant responses, coupled with advances in the dynamic modification of light quantity and quality in different phases of growth may contribute to the efficient utilization of LED lighting technologies in plant cultivation in closed environments. Greenhouses and vertical farms have different lighting requirements.

Indoor vertical farms have numerous layers to multiply the growing area, very short distances to fit as many layers as possible, low head and high uniformity requirements, no sunlight contribution and can grow seedlings and small plants and vegetables. LED lights enabled the vertical concept to go from pilot to commercial. LED efficiency and the lack of radiated heat were the key enablers. Growers could go from 7 to 8 layers with linear fluorescent lighting to 12 to 14 layers with LEDs in a building with say, 25-ft-high ceilings.

Greenhouses have high distances, high light output, have transparent ceilings to let the sunlight in and can grow all types of plants, vegetables, flowers. LEDs allow increased production during the winter months, and are able to significantly extend the growing season even in a relatively warm region of the globe. When light enters the glass, three things happen with the beam of light are. One part goes directly through, one part is reflected and one part is absorbed. Tinkering with the components and the coating can decrease the reflection and absorption. An anti-reflection coating will give a few percentage more transmission. The same goes for glass containing less iron. Finally the glass surface can be influenced, resulting in a high or low haze the extent in which light becomes diffuse. Diffuse light results in more and faster production. Because of that light will also reach the lowest leaves; resulting in more photosynthesis and more generative growth. Also, LEDs are cool light sources and, as such, can be placed close to crops or within a canopy to light leaves that would normally receive little natural or supplemental light. This means that interlighting has the potential to increase yields more than the same amount of light added at the top of the canopy. The technique produces tasty fruit and extends the productive life of the plant (Davis, 2015). LED is a micro-chip, so it fits easily into any application and can increase freedom in any optical design. Mobile lighting systems can be used to light crops. This implies that fewer lamps could be needed to light a given area, which would greatly reduce installation costs. Li et al, (2014) showed that lettuce could be grown under mobile lights. Only half as many lamps were used as with the fixed LED treatment in their system. Mobile lights mounted on irrigation booms may provide an economically viable way of installing lamps, where only low doses of light are required, end-of-day light treatments or UVC/UVB treatments, End of day, day extension and night interruption LED lighting can be used effectively to control plant flowering, but the importance of the spectral composition of lights used for this application needs further trials (Kubota et al., 2012). It is possible to pulse the light in such a way as to deliver the correct amount of light energy to excite every photosystem. Unlike traditional lighting systems, LEDs can be turned on and off rapidly, hundreds of times per second. This creates the opportunity to potentially maximize the photosynthetic performance of crops while minimizing the energy inputs.

Our vertical farming systems

For our measurement we set up vertical farming, first time with HPS lighting, than with LED lighting. We detached 1,5 meter x 2 meter white-walled space for this.

For HPS lighting system we used two OSRAM NAV-T Super 400 W lamps with 50x50 reflector. For this lamps we had to build in a Ballast 400W for the appropriate power service with overheat protection. The distance between the lighting and the plants was 1 meter. The plants were grown in 30 pots and watered in every three days.

After a month the wall began moldy, so the ventilation had to be resolved. The environmental parameters we measured with TFA Dostmann thermo-hygrometer station. The station has a transmitter and a data logger part. The transmitter we set up in the vertical farming room, the data logger outside for control. For one month we collected the temperature and humidity data, the ten minutes measurements were averaged into daily data (Diagram 1.).

For the LED lighting we used Philips GreenPower LED Research module, including power supply and suspension. Each module individually replaceable and with an application we could tune in white, red, blue and far-red spectrums specific. For one month we collected the temperature and humidity data and compared with HPS system (Diagram 1.). The plants number we didn't change, but later we could double this number. The watering was nearly halved, so we make it in every fourth day. The ventilation we turned off.

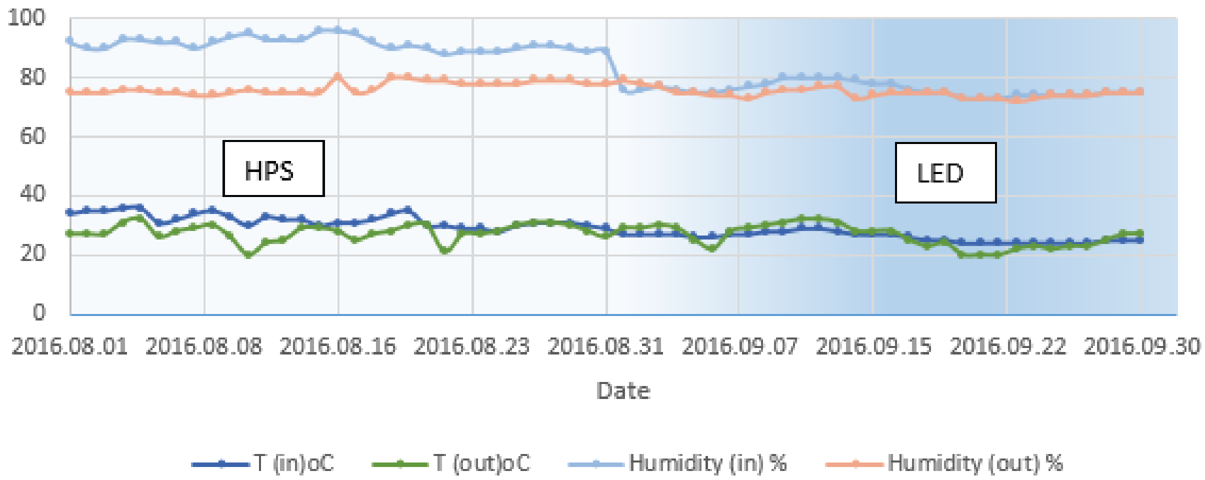

Diagram 1. - Weather data over one month for HPS and LED light treatment replication. Air temperatures (in and out) in degree celcius; relative humidity (in and out) in percentage. Source: Own data

Based on weather data, we can say that the HPS system increased the ambient temperature and the relative humidity more as the LED system. The electricity consumption of two systems are compared in Table 3

Table 2. – Comparison of our two vertical farming system, Source: Own data.

	HPS System	LED system
The total cost of investment (Ft)	85800	92400
Electricity costs for a month (Ft)	25080	7300

While the difference between the cost of investment systems is less than 10%, until then the LED system has reduced more than a third of the power consumption.

Light measurement and spectroscopy

The lighting we could measure with spectrophotometer for the spectral output, or with lux meter for illumination level. For measuring the total radiant flux in space of any light source we could use an Integrating Sphere, in a specific labour. During active use we could measure the spectral output with spectrophotometers. We used a Qmini Spectroradiometer, ranging from 400 to 1100 nm. It is suitable for reflectance testing of plants. Spectral reference measurements are required to calibrate black and white backgrounds, called real-background correction. For white calibration we used a white optical Teflon panel. It was difficult under field conditions to measure the same way. This means that measuring distance must be the same and the direction angle must be the same angle of direction in all cases. Even with racks it is not easy to reproduce. Therefore, we developed a compact measuring device for easier usability. This is a kind of clip, which can be fitted without damage onto the leaves. The clip keeps the leaf in a fix position, and in constant distance from the spectroradiometer. The spectroradiometer head is perpendicular to the leaf surface. The clip has an own lighting source, in forty-five degrees to the spectrometer. First we used halogen lamps, but later it could be a specific wavelength light source for more sophisticated measurements. With this clip we could measure faster, more specifically, easier, and without damage in the field.

Conclusion

LEDs equipped with driver chips could provide the benefits of operational flexibility, efficiency, reliability, controllability and intelligence for greenhouse lighting systems (Darko et al, 2014). Lighting programs are able to change the shape, size, productivity and even essential oil content of many leafy greens and herbs. The experiment we want to continue with develop lighting programs that change the nutritional values of crops. These measurements will help the handheld device described above, which provides standard conditions to help measurement accuracy.

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