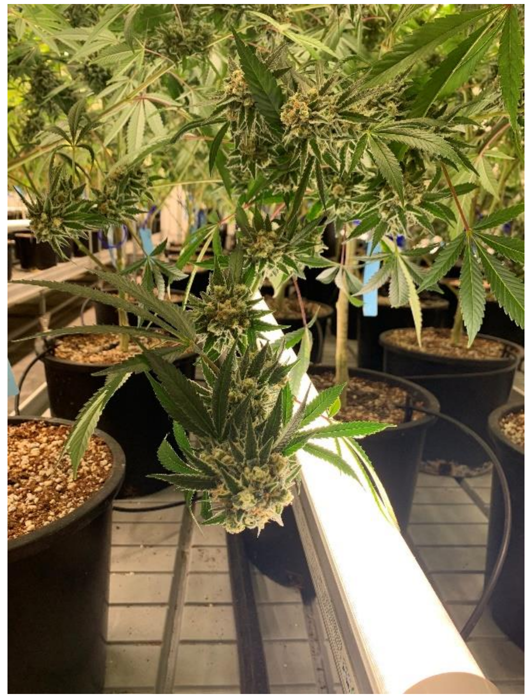
Beneath the Canopy: The Surprising Heat Dynamics of LED Lighting in Horticulture

The rapidly expanding application of LED lighting in controlled environment agriculture (CEA) has introduced numerous innovations, including under canopy lighting, which illuminates the lower parts of plants. Traditionally, lights are placed above the canopy, but dense foliage can limit light penetration to the lower laterals of the plants. Under canopy lighting is an advanced cultivation technique used in cannabis production that involves installing supplemental lighting systems beneath the upper canopy of the cannabis plants. Under canopy lighting has proven to improve photosynthesis, increase high quality bud yields, while reducing labor costs. Under canopy lighting dramatically improves light distribution within dense crop canopies. The attenuation of light within the canopy follows an exponential decline, with the strongest absorption of red and blue light occurring in the uppermost 20% of the canopy. As light penetrates deeper, the ratio of red to far-red light, as well as blue to green light, shifts, with green light contributing more significantly to photosynthesis in the lower leaves[1]. The concept of under canopy lighting is illustrated in the photo (right).



A significant advantage of under canopy lighting is the reduction in the need for fan leaf removal. Traditionally, growers spend considerable time and labor removing fan leaves to improve light penetration and airflow to the lower parts of the canopy. With under canopy lighting, light reaches these areas more effectively, minimizing the need for such labor-intensive practices. Additionally, the warmer air generated by lights inside the canopy naturally rises, enhancing airflow without the need for additional fans.

However, the addition of more lights to the growing environment creates a layer of complexity regarding heat management—both sensible and latent heat—and its effect on other environmental factors such as HVAC systems, humidity, CO_2 supplementation, and nutrient uptake.

[1] Slattery, R. A., & Ort, D. R. (2021). "Perspectives on improving light distribution and light use efficiency in crop canopies." *Plant Physiology*, 185(1), 34–48. doi:10.1093/plphys/kiaa006.

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Sensible and Latent Heat in Under Canopy Lighting

LEDs are generally more efficient than traditional lighting, but they still produce heat. The two types of heat relevant to horticulture operations are sensible heat—which increases air temperature—and latent heat—which influences humidity levels by affecting the phase changes of water, such as evaporation and condensation. Properly managing these heat forms is essential for maintaining optimal growing conditions.

HVAC Considerations

The sensible heat load introduced by under canopy lighting places additional demands on the HVAC system. Although LEDs emit less heat than high-pressure sodium (HPS) lamps, the heat generated by lights beneath the canopy adds to the overall thermal load. As a result, HVAC systems need to be optimized to manage heat from both above and below the plants. Effective airflow patterns and cooling strategies are essential to avoid overheating beneath the canopy while maintaining stable air temperatures across the entire grow space[2]. This may require adjustments to the ventilation system including changes to air circulation patterns.

Humidity

Latent heat refers to the energy absorbed or released during phase changes of water, such as evaporation. In horticulture, latent heat primarily impacts humidity levels. Unlike HPS lights, which emit significant radiant heat that dries the air, LED lights contribute less to air drying, which can lead to elevated humidity levels. Under canopy lighting further exacerbates this issue, as lights placed beneath the canopy can increase the overall moisture in the grow space without effectively drying the surrounding air.

The increase in humidity levels caused by latent heat must be managed through dehumidification systems. High humidity levels can create conditions for mold, mildew, and other plant diseases, particularly in densely packed grow environments. Furthermore, elevated humidity can reduce transpiration rates, slowing nutrient uptake and affecting overall plant health[3].

Maintaining an optimal vapor pressure deficit (VPD)—the difference between the moisture in the air and the moisture inside the plant—is essential for ensuring healthy plant growth. A balanced VPD encourages efficient water uptake and transpiration, which drives nutrient absorption. With under canopy lighting, growers must closely monitor humidity levels to prevent the negative effects of excessive moisture on plant growth.

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[2] A. Ikeda, Y. Tanimura, K. Ezaki, Y. Kawai, S. Nakayama, K. Iwao, H. Kageyama (2020). *"Environmental Control and Operation Monitoring in a Plant Factory Using Artificial Light."* Acta Horticulturae, DOI: 10.17660/ActaHortic., 151-158. 1992.304.16.

[3] Nelson, J. A., Bugbee, B. (2014). *"Economic analysis of greenhouse lighting: Light emitting diodes vs. high intensity discharge fixtures."* PLOS ONE, 9(6), e99010. doi:10.1371/journal.pone.0099010.

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CO_2 Supplementation

The introduction of under canopy lighting not only increases heat load but also alters the environmental conditions that influence CO_2 uptake. Plants use CO_2 for photosynthesis, and higher CO_2 levels can boost plant growth and yield. However, changes in temperature and humidity, due to the additional lighting, can complicate the efficiency of CO_2 supplementation.

The rise in ambient temperature from sensible heat can, in certain ranges, enhance the rate of photosynthesis and CO_2 uptake. Warmer air temperatures generally improve the diffusion of CO_2 into the plant's stomata (the pores on leaves used for gas exchange), provided the temperature remains within an optimal range. However, if temperatures rise too high, it can cause stomata to close, reducing CO_2 uptake and limiting photosynthesis. Thus, managing the heat from under canopy lighting is critical to ensuring that temperatures remain conducive to efficient CO_2 assimilation[4].

Additionally, higher humidity levels caused by latent heat can reduce stomatal conductance, further restricting CO_2 uptake. Stomatal conductance is the plant's ability to regulate the opening and closing of its stomata, and when humidity levels are high, stomata may remain closed for longer periods, limiting the plant's ability to absorb CO_2. To optimize CO_2 supplementation, it is essential to maintain the right balance of temperature and humidity, ensuring that both CO_2 diffusion and stomatal conductance remain at optimal levels[5].

Effective air circulation becomes even more important with the addition of under canopy lighting. Without adequate airflow, CO_2 may become unevenly distributed throughout the grow space, leading to areas of localized depletion or accumulation. Fans, vents, and ductwork should be adjusted to circulate CO_2 effectively across both the upper and lower canopies, ensuring uniform distribution and maximizing the benefits of CO2 supplementation.

Nutrient Uptake

The addition of under canopy lighting introduces more lighting sources to the grow environment, resulting in an increase in the overall heat load. This rise in heat, particularly sensible heat, will elevate the ambient air temperature, while latent heat affects humidity levels by influencing water vapor in the environment. Both factors play crucial roles in plant nutrient uptake because they directly influence transpiration—the process by which plants absorb water and nutrients through their roots.

When sensible heat increases due to additional lighting, the surrounding air temperature rises, which can enhance transpiration rates. Higher transpiration accelerates the movement of water

[4] Massa, G. D., Kim, H. H., Wheeler, R. M., & Mitchell, C. A. (2008). "*Plant Productivity in Response to LED Lighting*." HortScience, 43(7), 1951–1956.

[5] Kinhal V. (2023). "*The Role of Stomatal Conductance In the Global Carbon Cycle*." CID Bio-Science Weekly. April 24, 2023.

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and nutrients from the roots to the leaves, potentially leading to faster nutrient uptake and improved plant growth. However, if the air temperature becomes too high without sufficient cooling or airflow, excessive transpiration could cause plants to lose more water than they can absorb, leading to dehydration and nutrient imbalances. To mitigate this potential problem, HVAC systems must be carefully adjusted to maintain the ideal temperature for optimal transpiration and nutrient absorption[6].

In contrast, latent heat contributes to higher humidity levels by increasing moisture content in the air. Elevated humidity decreases the vapor pressure deficit. A low VPD reduces transpiration rates, slowing down nutrient uptake. This slower nutrient transport can lead to nutrient deficiencies and suboptimal growth if not properly managed. To offset the additional latent heat, growers may need to recalibrate irrigation and nutrient delivery systems, adjusting the concentration of nutrients in the solution to compensate for lower transpiration rates[7].

By closely monitoring both temperature and humidity, along with adjusting nutrient formulas, growers can counterbalance the effects of increased heat from under canopy lighting. Integrating these strategies helps ensure that plants receive the nutrients they need for healthy growth and development, despite the increased thermal load.

Conclusion

Under canopy lighting presents numerous advantages for modern horticulture, including better light distribution, improved photosynthesis in lower plant regions, more uniform crop development, and reduction of labor costs. However, the introduction of additional sensible and latent heat from these lighting systems creates new challenges in managing HVAC, humidity, nutrient uptake, and CO_2 supplementation. By addressing these challenges with precise climate control, tailored nutrient delivery systems, and optimized CO_2 management, growers can fully harness the benefits of under canopy LED lighting while maintaining optimal growing conditions.

Growers are encouraged to explore these advanced lighting solutions to stay competitive in the rapidly evolving field of controlled environment agriculture. The future of horticulture lies beneath the canopy where light, efficiency, and innovation come together to exceed the yield and efficiency of conventional overhead-only approaches.

[6] IBID.

[7] Poorter H, B Hler J, van Dusschoten D, Climent J, Postma JA., *"Pot size matters: a meta-analysis of the effects of rooting volume on plant growth."*. Funct Plant Biol. 2012 Nov;39(11):839-850. doi: 10.1071/FP12049. PMID: 32480834.

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