SPECIAL REPORT

STATE OF THE CANNABIS LIGHTING MARKET

FLUENCE BY OSRAM

CANNABIS BUSINESS TIMES

NOTE FROM FLUENCE CEO DAVID COHEN

As I sit down to write this year's introduction for the "State of the Cannabis Lighting Market" report, it's easy to see the difference a year can make in our high-growth industry. New states—some with a history of stigma toward the cannabis industry—are coming online. Consumer perception and acceptance of cannabis's potentially life-changing properties is more widespread. Consumers want to know more about the plant they're purchasing—and the experience it will create—beyond a simple THC percentage. New research is laying the foundation for a new wave of innovation that will transform the industry even further in the coming year. I can only imagine what I'll be writing in 2020.

At the center of it all—or more correctly, shining down on it all—is light. Cultivators around the world are adopting LED lighting systems in nearly every stage of plant growth. The increasing conversions to LEDs—whether through retrofitting or in initial facility design—says more about their viability than I or anyone else ever could. Better yet, early adopters are systematically ridding the industry of any lingering suspicions of the role LEDs play in critical areas like cannabinoid and terpene production, crop uniformity and yield, and energy efficiency.

It's even more encouraging to see how researchers, public officials and entire verticals are actively engaging with the cannabis industry. Around the world, thought leaders and policymakers are contributing to the growth of cannabis markets to ultimately serve consumers who are loudly demanding change to legal systems, health care and global sentiment. A better understanding of cannabis's benefits has only helped as data and preliminary research continue to change the minds of even the most skeptical of skeptics. Here at Fluence, we commend those who are helping the world grow, smarter.

As growers continue to invest their time and money into LED lighting, making informed choices now will dictate success in the future. Today, three in four growers are hinging lighting purchases based on energy efficiency and light intensity. Their preference for LEDs only further confirms that the industry is taking a long-term approach to growth and profitability that is built on sustainability and efficiency.

Fluence is proud to be the exclusive sponsor of *Cannabis Business Times*' fourth-annual "State of the Cannabis Lighting Market" report. I firmly believe the insights about LED lighting we've collected in this report are the cornerstone for a stable, sustainable and profitable cannabis industry.

> "AT THE CENTER OF IT ALL—OR MORE CORRECTLY, SHINING DOWN ON IT ALL—**IS LIGHT.**

DAVID COHEN
CEO, Fluence

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PUT RESEARCH IN THE SPOTLIGHT

WITH A NASCENT MARKET LIKE CANNABIS, objective data and research can be difficult to obtain. Opinions vary on everything from the most efficient cultivation practices to the most effective cultivars for treating specific ailments, but it's important to continue to challenge commonly held beliefs.

Cannabis Business Times has written about the lack of peer reviewed research, most recently in the September 2019 cover story, "The Science Void." Experts quoted in the article suggested that, while cannabis research remains a challenge to come by, cultivators set up their own studies, maintaining specific parameters for data points and keeping factors as consistent as possible for accurate results. We've also established our own studies here at *CBT*, including the following "State of the Cannabis Lighting Market" report, published since 2016.

By keeping questions consistent (with small modifications at times to obtain more meaningful results) and using nationally recognized, third-party researcher Readex Research to lead the study, *CBT* now has four years of data to compare, thanks to cultivators who have been willing to share their time and key aspects of their cultivation operations. This study has also been made possible by the generous support of Fluence. Key trends and notable results are highlighted throughout the following pages, comparing 2016 findings to what's true for cultivators today. Like many other aspects of the cannabis industry, significant changes have occurred over a fairly short period of time regarding how cultivators approach lighting, from the type of lighting technology they use during various plant-growth stages to how they determine which lighting option is best.

In addition to the report, two highly respected university researchers share insights into their studies on the lighting factors that affect cannabis and other plants. Although some research is available on the most effective lighting strategies for crop growth, there are always new things to discover. New technology and new questions have offered new insights, illustrating the importance of continuing to question and investigate previously held beliefs, and to study the rapidly evolving cannabis cultivation industry and its practices.

72%

OF RESEARCH PARTICIPANTS

NOTED THAT ***ENERGY EFFICIENCY*** AND ***LIGHT INTENSITY*** WERE THE MOST IMPORTANT FACTORS WHEN MAKING LIGHTING PURCHASES.

FACILITY

LED Usage, Interest Continue to Increase

THE FIRST YEAR (2016) *CBT* CONDUCTED THE "STATE OF THE CANNABIS LIGHTING MARKET" STUDY, 21% of cultivators who participated in the research indicated they used light emitting diodes (LEDs) in propagation, and even fewer used LEDs in the vegetation and flowering stages (17% and 15% respectively). Each year, LED use has grown faster than any other type of lighting technology, with double-digit growth from 2016 to 2019 in all stages of plant growth. Four years later, nearly half of all research participants (47%) now use LEDs in propagation, and nearly half also use them in the vegetation (46%) and flowering stages (45%). LEDs are now among the top two choices of lighting types throughout the plant's lifecycle. Among study participants, 39% said they are planning on implementing LED lighting during the flowering period within the next 12 months, which is up from 22% when *CBT* first asked this question in 2017.

However, the participants who indicated *they do not use LEDs for the cannabis flowering cycle and do not plan to in the next 12 months (or are unsure)* noted factors that prevented them from introducing LED technology. Top reasons included unproven technology (48%), too expensive (42%) and the payback/return on investment (ROI) is too long (21%).

LIGHTING USED IN PROPAGATION

	2016	2017	2018	2019	2016-2019 % point difference
T5 (high output/HO) lights (or other HO fluorescents)	65%	63%	51%	50%	↓ 15 pts.
light emitting diodes (LEDs)	21%	36%	47%	47%	↑ 26 pts.
high-pressure sodium (HPS) lights	16%	X	X	30%	↑ 14 pts.
metal halide (MH) lights - ceramic	10%	X	X	X	X
compact fluorescent lights	9%	19%	9%	10%	↑ 1 pt.
metal halide (MH) lights - quartz	6%	X	X	X	X
sulphur plasma lights	2%	X	X	X	X
magnetic induction lights	1%	11%	7%	3%	↑ 2 pts.
other	6%	21%	23%	11%	↑ 5 pts.

LIGHTING USED IN VEGETATION

	2016	2017	2018	2019	2016-2019 % point difference
T5 (high output/HO) lights (or other HO fluorescents)	37%	38%	28%	31%	↓ 6 pts.
high-pressure sodium (HPS) lights	31%	30%	25%	19%	↓ 12 pts.
metal halide (MH) lights - quartz	23%	15%	12%	12%	↓ 11 pts.
metal halide (MH) lights - ceramic	20%	31%	24%	26%	↑ 6 pts.
light emitting diodes (LEDs)	17%	36%	46%	46%	↑ 29 pts.
compact fluorescent lights	3%	X	X	X	X
sulphur plasma lights	2%	5%	2%	2%	0 pts.
magnetic induction lights	2%	4%	3%	3%	↑ 1 pt.
other	8%	8%	7%	6%	↓ 2 pts.

Total may exceed 100% because respondents could select all that apply. 2018 results are based on the 114 research participants who grow only indoors and/or in greenhouses using supplemental lighting. 2017 results are based on the 294 research participants who grow only indoors and/or in greenhouses using supplemental lighting. 2016 results are based on 117 research participants who grow indoors and/or in greenhouses (with or without supplemental lighting) and/or outdoors.

LIGHTING

PROPAGATION

Despite the growth in LEDs, half of survey respondents (50%) use T5 (high output/HO) lights or other HO fluorescents in the propagation stage, while 47% of participants use LEDs in propagation. The number of cultivators using T5 lights in propagation has decreased by 15% since *CBT* first asked about lighting used in the 2016 study.

VEGETATION

LEDs are now used by more cultivators (46%) than any other lighting method in vegetation, which is a significant change since *CBT* introduced the study in 2016, when LEDs were ranked fifth in terms of lighting choices for veg. The second-most common lighting technology used is T5 (high output/HO) lights (or other fluorescents), as 31% of cultivators noted they use this type of lighting during this growth stage, while 26% use ceramic metal halide (MH) lights.

FLOWERING

According to this year's research, the majority of cultivators (51%) use high-pressure sodium (HPS) in the flowering stage. A significant portion also use LEDs (45%), whereas in 2016, just 15% of growers indicated they used LEDs at this growth stage.

LIGHTING USED IN **FLOWERING**

	2016	2017	2018	2019	2016-2019 % point difference
high-pressure sodium (HPS) lights	62%	68%	51%	51%	↓ 11 pts.
light emitting diodes (LEDs)	15%	36%	45%	45%	↑ 30 pts.
T5 (high output/HO) lights (or other HO fluorescents)	8%	7%	7%	7%	↓ 1 pt.
metal halide (MH) lights - ceramic	7%	13%	8%	13%	↑ 6 pts.
metal halide (MH) lights - quartz	5%	6%	3%	9%	↑ 4 pts.
compact fluorescent lights	3%	X	X	X	X
sulphur plasma lights	1%	5%	1%	3%	↑ 2 pts.
magnetic induction lights	1%	3%	4%	3%	↑ 2 pts.
other	5%	9%	9%	9%	↑ 4 pts.

Total may exceed 100% because respondents could select all that apply. 2018 results are based on the 114 research participants who grow only indoors and/or in greenhouses using supplemental lighting. 2017 results are based on the 294 research participants who grow only indoors and/or in greenhouses using supplemental lighting. 2016 results are based on 117 research participants who grow indoors and/or in greenhouses (with or without supplemental lighting) and/or outdoors.

Portion of growers who said they are planning on implementing LED lighting **during the flowering** period within the next 12 months:

2019
39%

2018
33%

2017
22%

WHY CULTIVATORS BUY: REASONS ARE CHANGING

In 2018, study participants noted that *light intensity*, *manufacturer's customer service reputation* and *scientific research supporting product development* were the top three factors they considered when making lighting purchases, rating them as "very important" or "important." The rankings have changed greatly since last year, however. This year, *light intensity* still ranks No. 1 in terms of importance, but tied with it is *energy efficiency* (72%), which was rated lower in 2018 (68%) compared to other factors. Tied for second this year are *light spectrum*, which ranked fifth in 2018, and *price* (68%), which was rated lower in 2018 (66%).

DATA REMAINS A CONSTANT FOR CULTIVATORS

Decisions are, of course, more informed and potentially made easier when sufficient data exists to help guide cultivators. Since *CBT* posed the question, "What types of data does your operation collect in its cannabis growing environment?" in 2017, data collection has remained a strong and steady constant for cultivators. The vast majority of participants (96%) noted they collect data on some aspect of cultivation. The top three data points that cultivators measure are *humidity* (86%), *ambient room temperature* (79%) and *relative humidity* (77%). However, other metrics that cultivators indicated were important included *nutrient solution pH*, *yields* and *CO_2 concentration*—all tracked by more than 60% of study participants. Lighting-specific data is also important: 60% of cultivators noted they track *light intensity (photosynthetic photon flux density, or PPFD) and/or light quality (spectrum)*, which is consistent with the factors they consider when making purchasing decisions.

The top three outside sources for gathering lighting cultivation information remain unchanged, with industry publications, industry peers, and industry research and studies being the most turned-to resources.

LED REBATES: FEWER EXPLORE THE COST-SAVING OPTION

Between the 2017 and 2018 "State of the Cannabis Lighting Market" studies, the number of participants indicating they explored utility rebate incentives for LEDs increased from 40% to more than half (51%) of all respondents. This year, that number decreased, as only 36% of participants indicated that they pursued this option to offset the expense of implementing LED solutions. Only 12% of participants received rebates while 7% did not. Another 17% said they considered rebates but didn't submit them yet. A majority of survey participants did not explore utility rebate incentives to subsidize the cost of LED solutions (64%), with 35% saying they were not aware of rebate programs.

TOP 10 MOST IMPORTANT FACTORS WHEN MAKING LIGHTING PURCHASES

These 10 items were ranked as "important" or "very important" by 2019 study participants:

Total may exceed 100% because respondents could select all that apply.

DATA COLLECTED	2017	2018	2019	2017-2019 % point difference
relative humidity	81%	71%	77%	↑ 4 pts.
humidity	x	82%	86%	↑ 4 pts. (from 2018)
ambient room temperature	79%	83%	79%	0 pts.
nutrient solution pH	76%	70%	76%	0 pts.
CO_2 concentration	62%	72%	66%	↑ 4 pts.
yields	x	67%	67%	0 pts. (from 2018)
media pH	58%	61%	57%	↓ 1 pt.
nutrient solution electrical conductivity (EC)	55%	51%	50%	↓ 5 pts.
light intensity (PPFD)	50%	51%	50%	0 pts.
light quality (spectrum)	41%	30%	38%	↓ 3 pts.
media EC	39%	46%	38%	↓ 1 pt.
leaf surface temperature	30%	34%	40%	↑ 10 pts.
root zone temperature	29%	32%	31%	↑ 2 pts.
air speed	18%	19%	26%	↑ 8 pts.
other	16%	10%	4%	↓ 12 pts.
NET: Light intensity (PPFD) and/or light quality (spectrum)	57%	59%	60%	↑ 3 pts.
indicated at least one	95%	95%	96%	↑ 1 pt.
none	5%	5%	4%	↓ 1 pt.
no answer	0%	0%	0%	0 pts.

Total may exceed 100% because respondents could select all that apply. 2018 results are based on the 114 research participants who grow only indoors and/or in greenhouses using supplemental lighting. 2017 results are based on the 294 research participants who grow only indoors and/or in greenhouses using supplemental lighting.

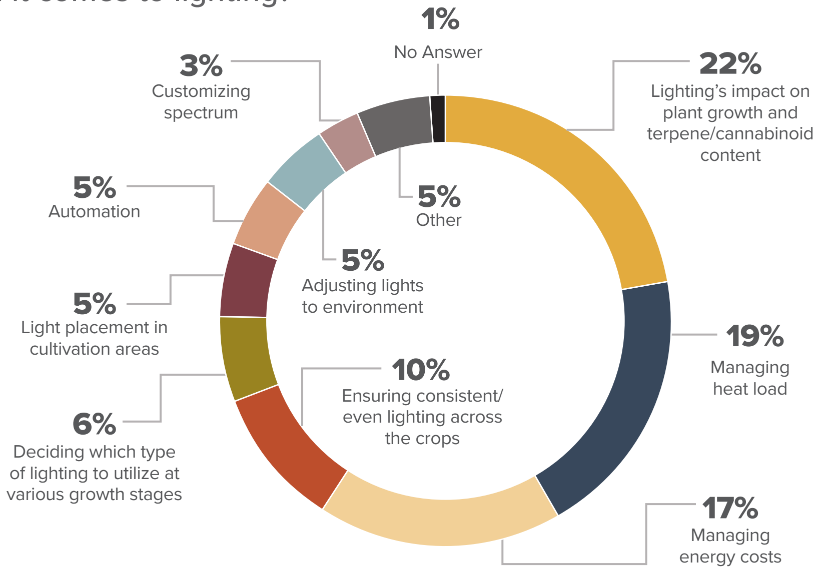
LIGHTING CHALLENGES: TOP 3 REMAIN THE SAME

While there have been year-to-year differences and significant changes in four-year comparisons with other data points noted in this year's lighting study, lighting challenges faced by cultivators have remained fairly consistent. The top three pain points remain the same: *lighting's impact on plant growth and terpene/cannabinoid content*, *managing heat load*, and *managing energy costs*. *Ensuring consistent/even lighting across the crops* (10%) ranked slightly higher this year compared with 2018 (6%). Participants seem a bit more confident in *deciding which type of lighting to utilize at various growth stages* this year: 6% of research participants indicated this as the biggest pain point in their cultivation's lighting operations this year, compared to 13% last year.

TOP 3 SOURCES OF HOW **CULTIVATORS GATHER LIGHTING INFORMATION**

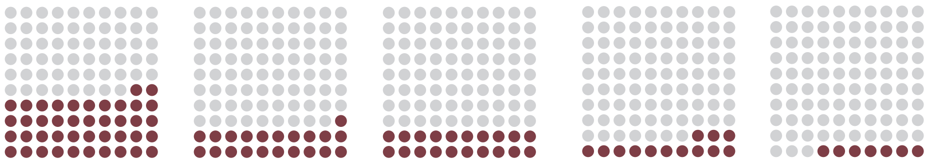
1. INDUSTRY PUBLICATIONS
2. INDUSTRY PEERS
3. INDUSTRY RESEARCH AND STUDIES

What is your cannabis cultivation operation's **greatest challenge** when it comes to lighting?



LIGHT METERS USED

2019	2019	2019	2019	2019
42%	**21%**	**20%**	**13%**	**7%**



Quantum sensor/ PAR meter (μmol/ m2/s)	Photometer/lux meter (footcandles)	Spectroradiometer (μmol/m²/s/nm)	Pyranometer (watts/m²)	Other
Growth vs. 2016: ↑ **15% pts.**	Growth vs. 2016: ↓ **6% pts.**	Growth vs. 2016: ↑ **18% pts.**	Growth vs. 2017: ↓ **7% pts.**	Growth vs. 2016: ↓ **2% pts.**

◄ *Total may exceed 100% because respondents could select all that apply.*

2019
73%
Indicated at least one

2019
26%
None – operation does not measure the amount of light its crop receives/ don't use light meters

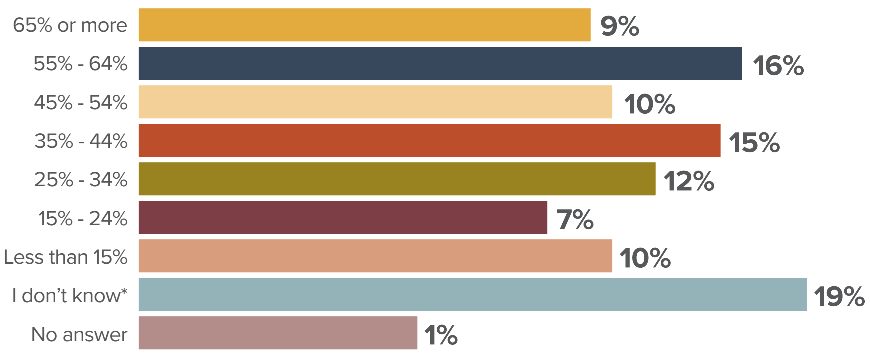
2019
1%
No answer

FACILITY DETAILS: PRODUCTION & EFFICIENCIES

Other data points are significant for cultivators to determine their production efficiencies (or inefficiencies). For more than a quarter of cultivators who participated in the study (26%), lighting comprises a majority of their cultivation operation's electricity costs, at 55% or more of the overall bill. Another 26% of participants say 35% to 54% of their electricity bill is spent on lighting. About 20% either don't know the costs or don't separate it out, either because they don't oversee that aspect of the facility or don't track it.

The majority of cultivators (51%) who participated in this year's research indicated their cannabis cultivation operation's average kilowatts per hour output in 2018 was less than 500,000, with most (39%) falling in the less-than 250,000 range.

What percentage of your cannabis cultivation operation's **electricity costs** were spent on lighting in 2018?



Responses include those who were unable to separate from total electricity costs

What was your cannabis cultivation operation's **average kilowatts per hour** (kWh) output in 2018?

75 million or more	6%
50 - 74.9 million	3%
25 - 49.9 million	3%
10 - 24.9 million	3%
5 - 9.9 million	3%
3 - 4.9 million	3%
2 - 2.9 million	2%
1 - 1.9 million	3%
750,000 - 999,999	7%
500,000 - 749,999	7%
250,000 - 499,999	13%
less than 250,000	39%
no answer	9%

CULTIVATION FACILITY SIZE

What is **the area** of your operation's total plant canopy?

100,000 sq. ft. or more	11%
50,000 - 99,999 sq. ft.	5%
25,000 - 49,999 sq. ft.	11%
10,000 - 24,999 sq. ft.	14%
2,500 - 9,999 sq. ft.	19%
less than 2,500 sq. ft.	40%

CULTIVATION FACILITY TYPES

In what **type of facility** does your operation grow cannabis?

75% indoor facility

30% outdoors

20% greenhouse with supplemental lighting

9% greenhouse without supplemental lighting

83% NET: indoor facility and/or greenhouse with supplemental lighting

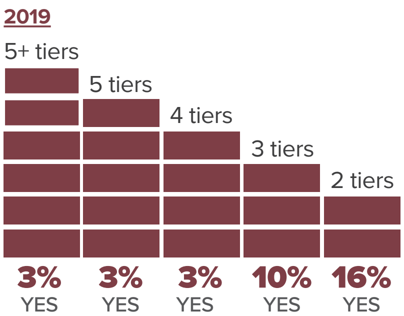
*Total may exceed 100% because participants could select all that apply. To examine **lighting** trends among cultivators, CBT's research looked at the responses of 83% of participants (149) who grow indoors and/or in greenhouses using supplemental lighting. Responses from participants who only grow outdoors or in greenhouses without supplemental lighting were excluded from the final report.*

VERTICAL CANNABIS CULTIVATION

Usage of vertical rack systems has increased slightly since *CBT* first asked (in the lighting market study in 2017) if cultivators used tiers and in which growth stage: 35% of participants noted they use systems in the vegetation stage this year (compared to 31% in 2017) and a fifth of study participants (20%) indicated they use vertical farming in the flowering stage (compared to 13% in 2017). Many who do not use tiers in cultivation now are considering them in the future, with 28% of participants considering implementing vertical rack systems in the vegetation stage in the next 12 months, and 23% considering the systems for flowering.

VERTICAL FARMING-VEGETATION

Does your cannabis operation **use vertical rack systems** for cannabis *vegetation* (NOT including propagation?)



35% NET: Yes

65% NET: No

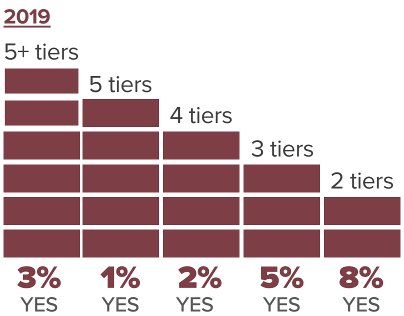
28% No, but **considering doing so** in the next 12 months

38% No, and **not considering doing so** in the next 12 months

0% No answer

VERTICAL FARMING-FLOWERING

Does your operation **use vertical rack systems** for cannabis *flowering*?



20% NET: Yes

77% NET: No

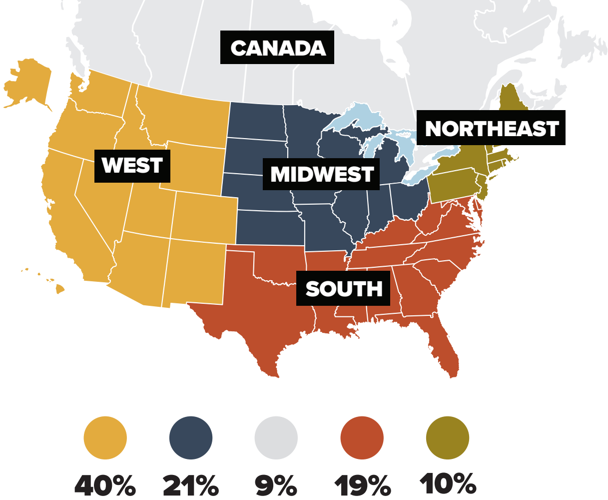
23% No, but **considering doing so** in the next 12 months

54% No, and **not considering doing so** in the next 12 months

3% No answer

GEOGRAPHIC DISTRIBUTION

OF RESEARCH PARTICIPANTS



ABOUT THE RESEARCH & PARTICIPANTS

Third-party researcher Readex Research conducted the study and compiled the data for the "2019 State of the Cannabis Lighting Market" report. The survey was sent to *Cannabis Business Times* magazine subscribers with known email addresses and/or e-newsletter subscribers located in the United States, Canada, or other (unknown) North American locations in August and September 2019.

Results are based on 149 respondents who own or work for an operation that cultivates cannabis indoors and/or in greenhouses with supplemental lighting, unless otherwise indicated. Cultivators who grow outdoors or in greenhouses without supplemental lighting were excluded from the results. The margin of error for percentages based on the 149 respondents who indicated they own or work for a cultivation operation that grows cannabis in an indoor facility and/or greenhouse with supplemental lighting is approximately ±7.9 percentage points at the 95% confidence level.


Light-emitting diode (LED) technology has given researchers a new tool to study plant photobiology.

(NOT) PAR FOR THE COURSE

Updated research shines new light on photosynthesis.

BY **JOLENE HANSEN**

For nearly 50 years, scientists and horticulturists have accepted that wavelengths of light used in photosynthesis are limited to a range of 400 to 700 nanometers. This definition of photosynthetically active radiation (PAR) was solidified in the early 1970s with the publication of Dr. Keith McCree's McCree Curve.

Now, thanks to decades of research at several laboratories, including Utah State University's Crop Physiology Laboratory, a new understanding of PAR has emerged.

Led by director Bruce Bugbee, Ph.D., professor in the Department of Plants, Soils and Climate, USU research is redefining PAR and transforming scientific understanding of light quality, commonly thought of as ratios of color.

ALL PHOTOS COURTESY OF FLUENCE UNLESS OTHERWISE NOTED

Well-known for his pioneering NASA-supported research on crops in space, Bugbee has studied spectral effects on photosynthesis and plant morphology for 40 years. Once focused on traditional crops, these carefully controlled studies now extend to cannabis.

Despite McCree's place in science, Bugbee says USU research provides evidence of photosynthesis from photons beyond the 700 nanometer limit of the McCree Curve.

SHIFTING THE DISCUSSION SURROUNDING LIGHT QUALITY

As a first step toward understanding Bugbee's research, he stresses the importance of separating the effects of light quality into effects on photosynthesis versus effects on plant shape.

Bugbee says there's an unwarranted emphasis on red/blue or narrow-band light for photosynthesis. As a result, narrow-band light became popular in LEDs, negating the power of the entire spectra of light. "The effect of color on photosynthesis is way overrated," he says. "Conversely, the effect of color on plant shape is underrated."

He explains that light quality has only a small effect on photosynthesis, but a large effect on plant shape. And the effect of light quality on plant shape varies widely among species.

Bugbee hopes to shift the conversation on the effects of color ratios away from photosynthesis and toward plant shape and secondary metabolism.

Regarding photosynthetic effects, he points to light intensity (aka light quantity). "Photosynthesis is exquisitely sensitive to intensity," he explains.

LEVERAGING TECHNOLOGICAL ADVANCES

At the time of McCree's work, technology for studying spectral effects was primitive by modern standards. "As great a scientist as McCree was, and I knew him personally, he didn't have LEDs," Bugbee says.

Bugbee equates the advent of LED (light-emitting diode) technology to the development of the telescope for studying astronomy. "There are lots of examples in the history of science of major breakthroughs in measurement technology that allowed scientists to test new things," he says. "LEDs are like that for plant photobiology."

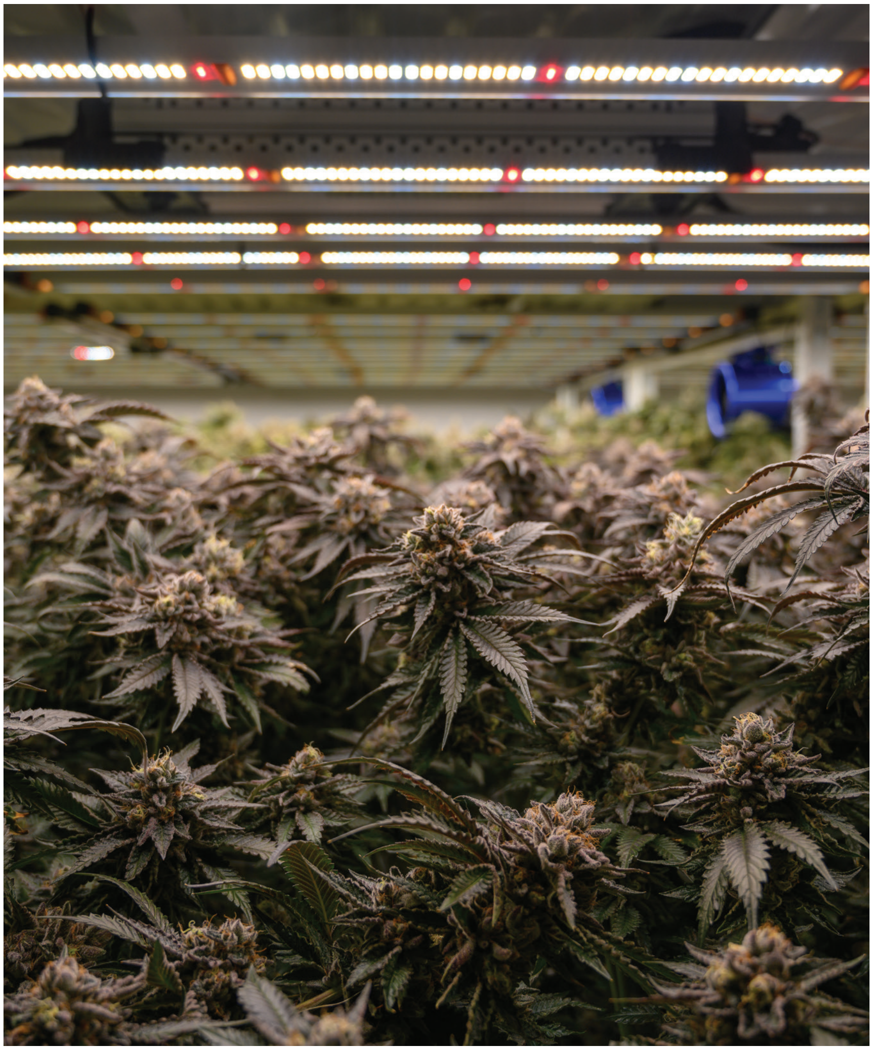
McCree used prisms and filters to study one wavelength at a time on a single leaf. The USU lab uses high-intensity lighting and can easily dim lights or change ratios of color. Rather than single leaves and single wavelengths, they study whole plants in small, controlled-environment communities where multiple layers of leaves capture photons.

With these technological advances, the USU team has evidence that photosynthetic photons extend beyond 400 to 700. As an example, Bugbee points to far-red photons, barely visible to the human eye at 730. By themselves, they do nothing, he says, but synergism occurs when combined with other wavelengths.

"In addition to photosynthesis, far-red photons are a powerful tool to manipulate plant shape," Bugbee says. In lettuce, they cause plants to grow wider with larger leaves. But unfortunately, most other plants respond to far-red with excessive stem elongation, he says.

MODIFYING THE DEFINITION OF PAR

Bugbee hesitates to claim he's redefined PAR, but he says manuscripts currently in review in peer-reviewed scientific journals suggest a new definition. Until accepted for publication, the papers remain confidential, but he believes they have the potential to



New research from Utah State University is expanding previous definitions of photosynthetically active radiation (PAR) and how light affects photosynthesis and plant morphology.

become as profound as the McCree paper 50 years ago.

"If we start getting people to think about an expanded range of wavelengths for photosynthesis, that's a big deal," he says. "We are not yet sure how much it should be expanded, but it may be as much as 350 to 750."

Bugbee says he's less certain about the lower range, due to less data for UV photons, but the upper end should be at least 730 or 740. Expect the new definition to have sloping sides, unlike the McCree Curve. "It's not a sharp cutoff," he adds.

Researchers are continuing to study the impact lighting has on cannabinoid content, quality and yield.

FOCUSING ON LIGHT EFFICACY

Bugbee advises cannabis cultivators to stop worrying about colors and concentrate on efficacy.

He explains that when output and input are compared using like units—such as watts out versus watts in—the resulting ratio is called efficiency. But photons cause photosynthesis, not watts. In horticultural lighting, the units are micromoles of photons out per joule of energy in, and when output and input units differ, the resulting value is called efficacy.

Bugbee says the best lighting manufacturers test the efficacy of their fixtures themselves and test through independent third-party labs as well.

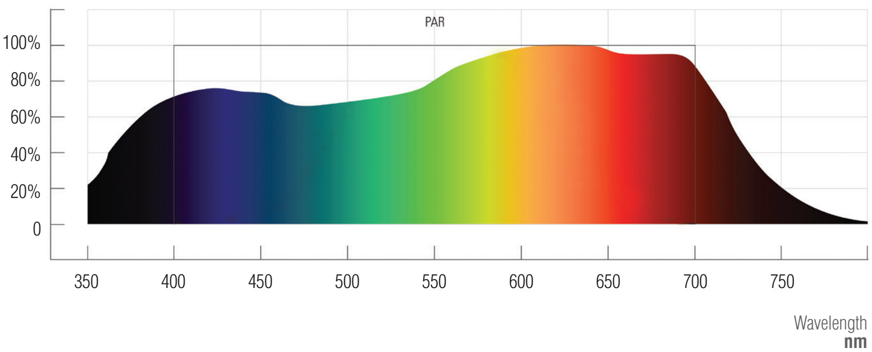
"Fixture efficacy, not spectral quality, is paramount for plant growth," he adds.

As a benchmark, Bugbee says high-pressure sodium lights put out 1.7 micromoles per joule, similar to LEDs five years ago. Today's LEDs now run from an efficacy of 2.6 to 3.1 micromoles per joule, and the technology is still maturing.

He recommends growers consult the DesignLights Consortium website at designlights.org. The nonprofit lists the photosynthetic photon efficacy (PPE) of fixtures based on third-party testing. "PPE is an important metric for growers when selecting lights," Bugbee says.

"After selecting an effective fixture (micromoles per joule), the fractions of blue and far-red photons can be fine-tuned to alter plant shape," he says.

PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)



Previous definitions of PAR limited the range to 400 to 700 nanometers, but researchers believe the range could be expanded to potentially 350 to 740 nanometers. *Data courtesy of Fluence*

MOVING FORWARD WITH NEW UNDERSTANDING

As Bugbee's research continues, he says two issues remain center stage. "The potential to expand the range of wavelengths for photosynthesis is quite fundamental to all plant biology. A second thing is a better understanding of manipulation of spectral quality on plant shape."

Regarding cannabis, he shares that the USU lab is systematically testing hypotheses about cannabis growth, yield and quality. That includes studying the manipulation of wavelengths to affect cannabinoid quality and yield.

While well-aware of the commercial implications of the research, Bugbee says that's not foremost in his mind. "We're more interested in elucidating fundamental plant-growth responses to light and the definition of photosynthetic photons," he says. "We're re-examining our understanding of some fundamental principles. This thing we thought we had exactly right for 50 years, now we're saying that wasn't exactly right."

JOLENE HANSEN is a freelance writer and frequent contributor to GIE Media publications. Reach her at jolene@lovesgarden.com.

HANSEN HEADSHOT COURTESY OF JOLENE HANSEN

BY **HAYLEY CLARK**

LIGHT BULB MOMENTS

How growers can use measurement standards and light mapping to increase efficiency and consistency


Measuring light across multiple locations between plants will return a more detailed light map.

PHOTO COURTESY OF FLUENCE

The idea that effective lighting is vital for cannabis cultivation is hardly earth shattering, but as the industry advances, there is always more to learn, more tools available and more improvements to be made.

From the importance of lighting measurement standards to light mapping and increasing efficiencies, the best cultivators are always those who never stop learning. Here, Dr. Mark Lefsrud, an associate professor at McGill University who leads the institution's Biomass Production Laboratory, shares best practices growers should consider when lighting their crops.

How can growers apply a lighting measurement standard to cannabis?

A lighting measurement standard is an industry specification that ensures all cultivators and other parties are using the same unit measurements for lighting systems. These standards are a universal lighting language so that the industry conducts all testing, reporting and comparing of results in the same way, Lefsrud says.

He advises cultivators who wish to follow lighting measurement standards to look to the North Central Extension and Research Activity–101, or NCERA-101, group, which outlines minimum reporting guidelines, including both what to measure and how to measure. Alternatively, the American Society of Agricultural and Biological Engineers and the DesignLights Consortium both offer useful standards for growers.

To test lighting levels, most growers will generally use both a pyrometer, which measures the total amount of energy available in a light in watts per square meter, as well as a quantum sensor, which measures photosynthetic photon flux density, which is essentially how much photosynthetically active light the plant is receiving. Neither system is perfect, but using both gives a better understanding of lighting performance.

An effective go-to sensor is a spherical underwater quantum sensor, which mitigates common issues with measurement, such as inconsistent light streams and imperfectly angled lights and sensors. However, growers can produce a clear light map by investing in any quality sensor product as long as they use it correctly.

What is light mapping and why is it important?

Light mapping is the process of using sensors to measure light at key locations throughout a grow, Lefsrud says. As most cultivators plant in a grid structure, this usually means measuring light at every single plant location. For a more detailed picture, growers can add multiple points in between plants.

With the goal of uniformity throughout plant growth, light mapping is an essential tool to monitor what's reaching the plant at each stage throughout its lifecycle. For example, if growers notice areas in their light map that are overbright or too dark in their grid, they can adjust their hardware to create uniform brightness before these areas can cause inconsistent growth. "The game of the light installer is to try to make it as uniform as possible," Lefsrud says, adding that the grower's challenge is "to try to choose a location that's optimal for the plant—not too bright and not too dim."

But it's not always as easy as taking a measurement and calling it a day. Plants are simply too dynamic, and lights are too inconsistent. Some lights may have a stronger focal point and weaker outer coverage or vice versa, meaning that certain models can overlap one another and create inconsistent areas of light. Higher-end lighting fixtures tend to be more uni-

It is important to adjust hardware to avoid over-bright or over-dark spots that could affect yield and plant health.

> **"BLUE LIGHT CAN BE USED TO INDUCE FLOWERING BUT DOESN'T HELP VEGETATIVE GROWTH."**
>
> – DR. MARK LEFSRUD, ASSOCIATE PROFESSOR, MCGILL UNIVERSITY

form to mitigate this issue, Lefsrud says.

Meanwhile, plant growth impacts light-reading outcomes. Typically, growers will take a first reading at the ground level, another reading at the maximum height of the plant and a reading in the middle. This creates a vertical light gradient based on their growth rate.

This collection of results is a cultivator's light map, which he or she can use to choose the optimum light locations—placing and height—to maximize uniformity across the grow room, ensure everything is ready for harvest at the same time, and reduce lighting inefficiencies.

How can growers improve efficiencies in lighting?

One of the key actions growers can take to reduce inefficiency is to control the cooling system, Lefsrud advises. In LED (light-emitting diode) systems, if the diode fails early, it is almost always because it gets too hot, he says. "The thermal junction temperature on the back of that LED is what drives its efficiency, so if it can be really, really cold, then it drives really well and can last a really, really long period of time. But if you let it drift up to 100 or 200 or more degrees Celsius, then it dies."

Growers must also educate themselves on the latest industry knowledge. For example, it's still commonly believed that blue light is best for vegetative growth and that red light is best for flowering. But, according to Lefsrud, "our results say that's wrong. Blue light can be used to induce flowering but doesn't help vegetative growth." If cultivators work with outdated knowledge such as this, their careful efforts with the lighting spectrum can be less effective than expected.

Another question growers should consider is which lights are appropriate for their operation. LEDs are popular because they can provide efficiency increases of 40% to 50% and, in some cases, reaching up to 60%. But LEDs are not the only option. High-pressure sodium lights, for example, are still highly efficient, especially in the double-ended models, says Lefsrud. Meanwhile, single-ended models may be less efficient than double-ended lights, but they can offer wavelength capabilities not found in double-ended alternatives.

Cultivators must carefully research the current technology and decide on the most efficient product overall for their grow rooms.

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WHEN THE SKIES ARE GREY

BY **MICHELLE SIMAKIS**

Harvest Health & Recreation's lighting strategies have evolved as the Arizona-based company expands to new states with varying climates.

Harvest factors in the daily light integral (DLI) in its greenhouse operations to be sure plants get the optimal amount of light year-round.

Harvest Health & Recreation operates three cultivation sites, is waiting for state approval on another three and is constructing seven more with opening dates planned for 2020. That cross-country experience has taught the vertically integrated company based in Arizona that establishing growing and processing facilities in multiple locations is never a one-size-fits-all process when working with live plants.

Each Harvest indoor operation, greenhouse or outdoor grow requires different cultivation parameters to grow the best quality cannabis in the most efficient way, especially considering it is producing plants in climates as varied as Florida and Ohio.

Lighting is one of the most important aspects of a successful operation, and decisions are made carefully and early in the planning process.

When preparing a cultivation site in a new state, Harvest must first review the state regulations to determine what is possible, as some dictate the facility type, says Egan O'Keefe, eastern regional cultivation manager for Harvest. After that, the company considers the purpose and the location of each facility to determine lighting needs and what the daily lighting integrals (DLI) are, he adds.

DLI, an accumulation reading of how much photosynthetically active radiation (PAR) light a plant has received within an entire photoperiod, is most often a factor in greenhouses, where additional lighting is needed to supplement natural sunlight and compensate for when it's cloudy or when the days are shorter.

For example, Harvest currently is building a greenhouse in Maryland, O'Keefe says. To gain the most efficiency, the greenhouse is angled to maximize the amount of natural light hitting the glass roof "every single minute of the day," he says. But that's not enough.

"Obviously we're not working with the [full sun year-round], so we are going to look at the most energy efficient, but also [the most] advanced technology that we can utilize within the facility to optimize and replicate sunlight indoors" without being wasteful with energy, O'Keefe says. "Both of those are our big factors for determining our fixtures."

Harvest uses systems with photometric sensors that automatically cue lights at specific intensities so that optimal light conditions are maintained consistently without turning "the greenhouse operation into an indoor operation," O'Keefe says. DLI is a major part of that calculation.

"In Palm Springs, Calif., the DLI is incredible, and we only have to utilize our interruption light for a few hours in the evening and early morning. We use very low energy and are very cost efficient in those regions, versus in Ohio, we constantly have to run LED lights, and the signal sensors turn the interruption lighting on to maintain what we are trying to achieve while we have that significant cloud cover or rain," O'Keefe says.

That's why installing energy-efficient but powerful fixtures is crucial for Harvest's success. Since O'Keefe started working with the company four years ago, he has seen major advancements in lighting technology that have made a big impact on yield, cannabinoid profile quality and potency.

"There are outstanding products on the market, and now there are some exceptional companies building custom lighting fixtures to the request of the cultivator or the needs of the environment, between design and the makeup of these facilities and greenhouses," O'Keefe says. "LEDs are winning the race for the most optimal and efficient lighting method.

"There has been LED technology for a long time, but not [tailored to] … cannabis production," he continues. "All of that is taken into consideration and then put into the design of the new fixtures."

O'Keefe says lower-wattage fixtures and a much higher-quality lighting spectrum have been the most significant developments, as they have allowed the company to be more energy conscious and save money. He advises cultivators to keep up with the latest lighting research and technology available.

"If we use the latest and greatest, most efficient lighting methods, we can gain rebates from energy companies by being very efficient in the design of these huge commercial facilities," he says. "Lean on the advancements in technology while considering standard agriculture practices at the same time, and [know] that geographic location and DLI are the most important factors."

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