# Cannabis Cultivation Guide

Essential information on optimizing cannabis cultivation under **high-intensity LED lighting**

FLUENCE BY OSRAM

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## When light levels increase, how does a cannabis crop adapt and thrive?

## When one environmental condition changes, how do other conditions change in response?

# INTRODUCTION

In this guide, we document the best practices for managing the interdependence of lighting and other cultivation factors. When light intensity, light quality, or lighting-related heat levels change, every aspect of cultivation changes in response. To help you optimize your transition to LEDs, we worked with three horticultural consultants who specialize in environmental control, fertigation, and integrated pest management, respectively.

**After reading this guide, you will be able to:**

- **Successfully implement high-intensity LED lighting**
- **Understand the relationship between lighting, cultivation room enthalpy, and cooling and dehumidification.**
- **Be on track to save 5-10% on facility-wide electrical expenditures**
- **Consider an IPM strategy**
- **Optimize nutrient costs**
- **Evaluate capable horticultural consultants**

The Fluence Cannabis Cultivation Guide serves as an addendum to the **FLUENCE PHOTOBIOLOGY GUIDE.** Please refer to the photobiology guide for detailed information about photosynthetically active radiation (PAR), photosynthetic photon flux density (PPFD), photoperiodism, and other factors which affect horticultural lighting selection and implementation.

# MEET FLUENCE PARTNERS

## DR. NADIA SABEH

### President and Founder | Dr. Greenhouse

Dr. Nadia Sabeh is president and founder of Dr. Greenhouse, Inc., an agricultural and mechanical engineering firm that specializes in the design of HVAC systems for indoor plant environments. Dr. Sabeh first became interested in controlled environment agriculture (CEA) as an undergraduate, while working on a small shiitake and oyster mushroom farm in southern Idaho. For over 20 years, Dr. Sabeh has dedicated her education and career to helping farmers control their environments, allowing them to grow crops indoors, in greenhouses and in facilities that would otherwise be impossible or impractical to do so. She and her team have designed HVAC systems for facilities growing leafy greens, strawberries, cannabis, and vine crops all over the world. Dr. Sabeh has her PhD in Agricultural Engineering from the University of Arizona's Controlled Environment Agriculture Center (CEAC) and is a licensed Mechanical Engineer in the State of California. She currently serves as the chair of a new ASABE/ASHRAE co-sponsored committee that is developing the standard "HVAC for Indoor Plant Environments without Sunlight."

## SUZANNE WAINWRIGHT-EVANS

### Horticultural Entomologist | Buglady Consulting

Suzanne Wainwright-Evans is a horticultural entomologist specializing in integrated pest management. Suzanne has been involved in the Green Industry for more than 28 years with a primary focus on biological control and using pesticides properly. She is a graduate of the University of Florida with degrees in both Entomology and Environmental Horticulture. She has worked throughout the United States and internationally consulting to greenhouses, nurseries, landscapers, cannabis production and interiorscape companies. Additionally, Suzanne is frequently published in trade magazines, teaches workshops and lectures professionally to industry groups. Her lectures use her extensive library of insect photos and macro insect movies. She has spoken at the Smithsonian Institute as well as appeared on Growing a Greener World on PBS. She is the owner of Buglady Consulting, now in business for 18 years.

Suzanne lives in Pennsylvania with her husband, 1 dog and 5 cats in a log home built in the 1820's.

## DR. ALLISON JUSTICE

### Owner, Co-Founder | The Hemp Mine

Allison Justice graduated from Clemson University with a Ph.D. in Plant and Environmental Science. She has been VP of Cultivation for OutCo, a vertically integrated cannabis producer in San Diego, CA, for almost 3 years. During this time, Justice partnered with OutCo to form a hemp CBD extraction facility in her home state of South Carolina. Here, she owns and operates a 40-acre hemp farm. Through research and education, Justice is elevating the standards of cannabis and hemp cultivation both indoors/greenhouse and in the field. @Dr.Justice_grows

# LIGHTING

## CULTIVATING HIGH DLI, SHORT DAY FLOWERS

**For the purposes of commercial cultivation, cannabis is a "high DLI, short day" flowering plant:**

**HIGH DLI** – Cannabis "works" harder than most other plants and is able to use light to drive photosynthesis better than most other flowers

**SHORT DAY** – In nature, cannabis flowers during the fall to winter; this occurs when the dark periods extend to 12 hours per day, or more

Therefore, a long, 18-hour photoperiod application during stock production, propagation and vegetative stages, followed by the application of a short, 12-hour photoperiod during flower is a sufficient photoperiodic schedule for cannabis.

However, proper application of high-intensity lighting to maximize your cannabis plants' ability to tolerate high DLI is essential to maximize plant yields. It is also important to adjust your plants' photoperiodic schedule, depending on what cannabis strains you are working with.

### WHAT IS DLI AND PHOTOPERIOD?

Daily Light Integral (DLI) is a metric which analyzes the cumulative amount of photons of light a plant's canopy absorbs over the duration of the photoperiod (see sidebar [Figure 1]). Think of DLI as a "total" or accumulation measurement metric, as opposed to an instantaneous measurement, like PPFD.

**FIGURE 1**

$$DLI = \frac{\text{PPFD (X } \mu\text{mol/m}^2\text{/s)} \times 60 \text{ MINUTES/HOUR} \times 60 \text{ SECONDS/MINUTE} \times \text{PHOTOPERIOD (Hours)}}{1{,}000{,}000\ \mu\text{mol/mol}}$$

**GROW TIP:** If you are considering a greenhouse deployment, it is important to recognize light intensity stays constant indoors, while light intensity outdoors peaks when the sun reaches its zenith at midday. Light intensity also changes intermittently throughout the day due to environmental factors, such as overcast events. Further complicating DLI, it is also important to consider how the metric changes throughout the seasons, as days lengthen and shorten.

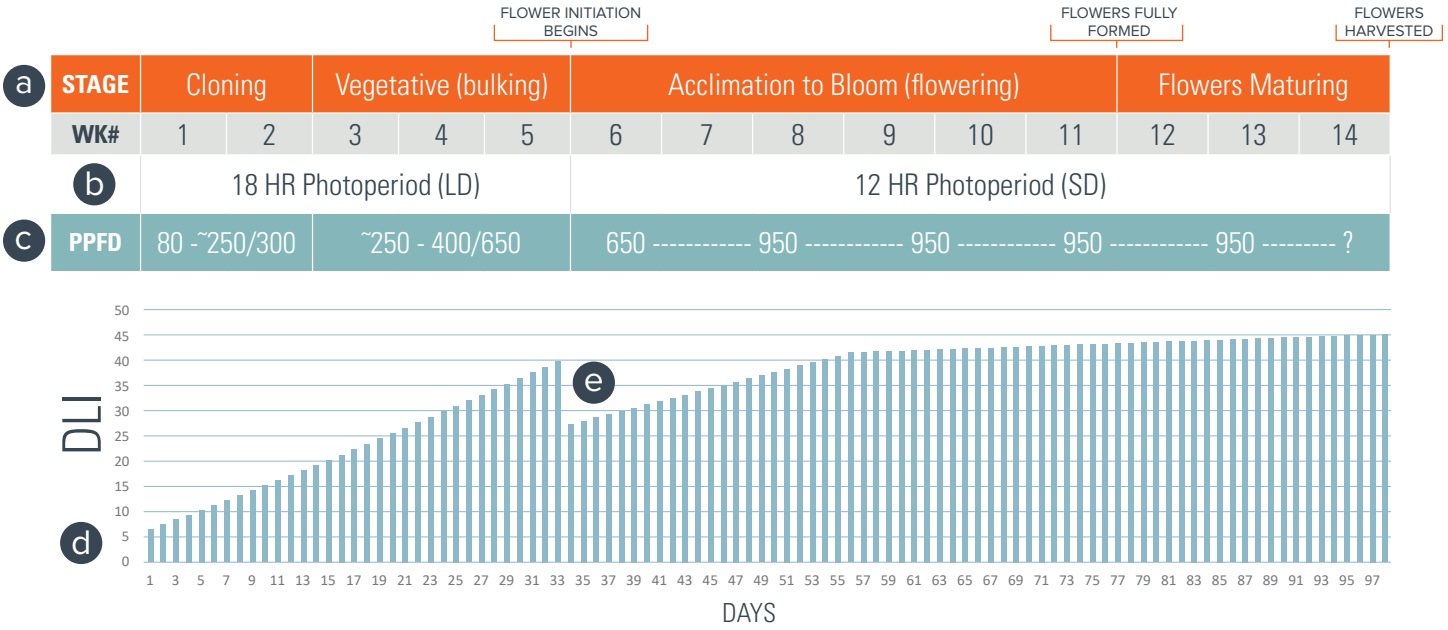
# PHOTOPERIODIC SCHEDULING

**Acclimating cannabis to light is a foundational aspect of a commercial grow environment.**

The DLI chart below [Figure 2] illustrates how much light accumulates in cannabis when scheduled properly on an 18-hour (propagation, vegetative, mother stages) to 12-hour (flower) photoperiod, mapped against a 14 week grow cycle.

## **PPFD** (µmol/m²/s) **& DLI**

**FIGURE 2**




This chart provides a schedule, which illustrates: (a) the development stages for cannabis in a cultivation setting, (b) optimal guidelines for photoperiod length by week, (c) optimal PPFD levels grouped by development stage, (d) cumulative DLI graphed against a day-to-day schedule (e) dip in DLI due to shortened photoperiod.

A critical aspect in understanding the chart is understanding the dip in DLI during the transition to flowering (i.e., generative stage; refer to weeks 5 and 6). Notice how the decrease occurs when shortening of the photoperiod begins at flower initiation [Figure 2b] while maintaining PPFD at 650 [Figure 2c] will result in a temporary reduction of DLI [Figure 2e].

The DLI dip [Figure 2e] occurs because cannabis requires time to photoacclimate in the flower room. Notice how DLI ramps back up within the next two weeks as PPFD is slowly increased (the 12-hour photoperiod remains constant) and begins to surpass previous DLI levels seen in the vegetative stage.

**GROW TIP:** When starting the photoacclimation process for flower, depending on the PPFD levels at the top of the plant canopy at the end of the vegetative stage, PPFD should match the top of the plant canopy at the beginning of flower. Cultivators should start to increase by 25-50 µmols per day or less, depending on the cultivar.

# DIALING IN YOUR ENVIRONMENT

**Recommendations in this guide are a baseline our team has developed for working with cannabis, and every cultivar tolerates environmental factors [Table 1] in each stage of growth differently.**

TABLE 1

| Development Stage | Propagation | | | | | Vegetative | Flowering |
|---|---|---|---|---|---|---|---|
| | Tissue Culture | Seed | | Cutting | | | |
| | Fixed | Fixed | Photoacclimated | Fixed | Photoacclimated | | |
| Light intensity (µmols/m²/s) | 60-80 | 150-250 | 150-350* | 150-250 | 150 -350* | 300-600 | 600+ |
| $CO_2$ (ppm) | Lab | 800 | 800 | 800 | 800 | 400-800 | 800-1400 |
| Temperature (deg. F, day:night) | Lab | **68°F - 72°F*** | **68°F - 72°F*** | 72°F - 80°F : 70°F - 78°F | 75°F - 80°F : 70°F - 75°F | 74°F - 84°F : 68°F - 76°F | 68°F - 84°F : 68°F - 78°F |
| Relative Humidity (%) | Lab | > 85% | > 85% | > 85% | > 85% | 55% - 75% | 50 - 60% |
| VPD as calculated from T/RH ranges | Lab | Figure 6 | | | | | |
| Leaf Temperature (deg. F) | Lab | 73°F - 78°F | 73°F - 78°F | 73°F - 78°F | 73°F - 78°F | 75°F - 78°F | 75°F - 78°F |
| Air speed (m/s) | Lab | 0.3 - 0.5 | 0.3 - 0.5 | 0.3 - 0.5 | 0.3 - 0.5 | 0.8 - 1.2 | 0.8 - 1.2 |
| EC (mS/cm) | Lab | 0.3 - 0.7 | 0.3 - 0.7 | 0.3 - 0.7 | 0.3 - 0.7 | 1.0 - 2.0 | 1.5 - 2.6 |
| Root Zone Temperature | | 75°F - 78°F | 75°F - 78°F | 73°F - 75°F | 73°F - 75°F | | |
| Nutrient ppm | There are important mineral ratios which need to be monitored. In many cases, growers have a different fertilizer regimen per stage of crop development. This strategy works for some, but is not generally recommended. You can be successful with having a baseline fertilizer mix which follows proper mineral ratios and rely on manipulation of EC during each stage to supplement nutrition concentration. More information can be found in the Nutrient section of this guide, and the pH chart and Mulder's Chart should be referenced in particular. | | | | | | |
| pH | | | | | | | |

***Temperature for germination should be gradually increased throughout the seed development stage***

Since set points in [Table 1] are baseline recommendations, it is important to monitor plants closely for signs of stress during the first few days of transition from each stage of growth to the other. Understanding how adjusting one set point in this chart affects each of the other set points is an important aspect of the rest of this guide. We have identified general issues, which tend to occur when utilizing high PPFD LED lighting for the first time.

# HVAC

Heating, ventilation and air-conditioning (HVAC) requirements change intricately when you increase light intensities in your environment. Dr. Nadia Sabeh designs horticultural HVAC systems and is very familiar with how high-intensity LEDs affect heat and energy usage. In this section, Dr. Sabeh provides advice on how to manage HVAC paired with high-intensity lighting for predictable production and maximum harvests.

## ENVIRONMENTAL CONTROL

As an environmental consultant, Dr. Nadia Sabeh designs horticultural HVAC systems for predictable production and maximized harvests. Her analyses go beyond simple temperature/humidity calculations to provide a holistic view of the growing space and a strong foundation for long-term success.

Dr. Sabeh calculates thermal conditions of a facility by assessing:

1. **Facility size** and **Canopy Area**
2. **Heat Sources** – lighting, other equipment, personnel, and infrared radiation from the sun
3. **Moisture Sources** – The sum of plant transpiration and other sources of evaporation (eg., open irrigation systems and growing media)

With the given facility information in hand, Dr. Sabeh begins an analysis that will ultimately lead to the management of vapor pressure deficit (VPD). Vapor pressure deficit is a measurement of the difference in saturation vapor pressure inside the cells of the leaves and the vapor pressure of the room's air at a given temperature and humidity level. VPD affects how plants cool themselves by releasing moisture into the air — a process known as transpiration. When VPD is high (i.e., warmer and/or drier), transpiration is rapid. When VPD is low (i.e., cooler and/or wetter), transpiration is slow. Transpiration critically affects the diurnal balance of heat and moisture in the cultivation space [Figure 3].

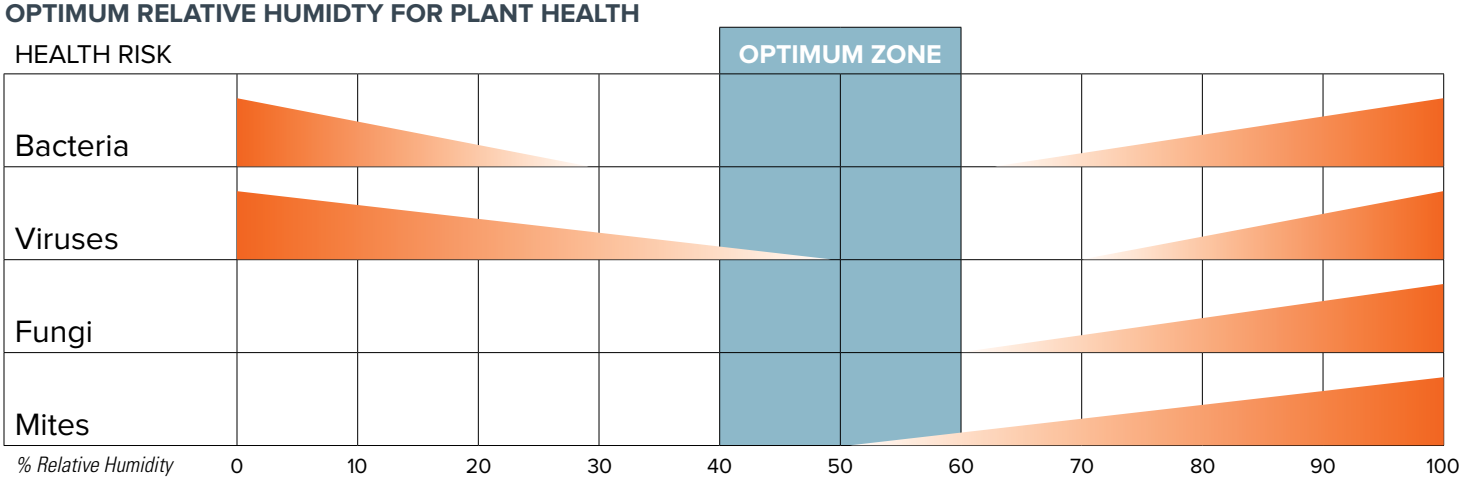
FIGURE 3: **RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES**

| Air Temperature | Relative Humidity | Vapor Pressure Deficit | Water Demand | Evapotranspiration |
|---|---|---|---|---|
| ↑ | ↓ | ↑ | ↑ | ↑ |
| ↓ | ↑ | ↓ | ↓ | ↓ |

**GROW TIP:** At very low VPD levels, a film of dew can form on the plants, providing a medium for mildew and disease. At very high VPD levels, plants will use more water for transpiration, affecting irrigation and nutrient usage.

FIGURE 4

**OPTIMUM RELATIVE HUMIDTY FOR PLANT HEALTH**




**GROW TIP:** Powdery Mildew prefers high VPD levels for spore dispersal. The Sterling Chart [Figure 4] indicates optimal relative humidity levels for minimizing adverse health effects

# SENSIBLE AND LATENT ENERGY

Under higher light intensities, targeting a specific vapor pressure deficit is an effective strategy for controlling transpiration and overall plant development. However, to effectively manage VPD, it is important to understand the dynamics of the grow room environment, including how and when heat and moisture are generated.

To perform this deeper analysis, Dr. Sabeh calculates the (1) sensible heat and (2) latent heat to evaluate the (3) phase change energy and (4) total enthalpy of a cultivation space.

1. **Sensible heat** is the form of heat that humans and plants can sense (or feel). It's measured with a traditional thermometer and is reported as "dry-bulb temperature".
2. **Latent heat** is the heat that is associated with phase changes between gas, liquid, and solid. Latent heat is trapped by water when it evaporates and is released by water vapor when it condenses to liquid. During this phase change process, the water does not change temperature, but the air temperature lowers during evaporation and rises during condensation.
3. **Phase change** occurs when a liquid gains energy (usually heat) and evaporates into a gas. An opposite phase change occurs when a gas loses energy and condenses back into a liquid.
4. **Enthalpy** is the total quantity of heat in a given volume. For a cultivation room, enthalpy is the sum of the sensible heat and latent heat.

Many HVAC designers neglect how latent heat and phase changes affect the temperature and humidity of the cultivation space. A transition from one phase to another takes more energy than a simple increase in temperature because breaking chemical bonds requires extra energy. To cool the grow room air, it must come into contact with colder surfaces that will absorb heat from the air. If those surfaces are cold enough, water vapor will condense out of the air onto those surfaces. "Dew point temperature" is the temperature at which water vapor condenses out of the air to form dew.

**GROW TIP:** LED fixtures create less heat than high-intensity discharge lamps (HID). That often means the cultivation space needs more dehumidification and less sensible-heat cooling. Overall, Nadia estimates total electricity costs are 5-10% lower when using LED fixtures.

**GROW TIP:** The formation of dew inside the grow room should be avoided. Note: Air conditioners and most dehumidifiers remove moisture with cooling coils that are at or below the dew point temperature. Insulate the building to prevent dew formation on the roof and walls at night and in cold climates.

# APPLIED PSYCHROMETRICS

A psychrometric chart (or psych chart) [Figure 5] helps visualize the properties and energy relationships of moist air, and can be used to assist in the design of cooling, dehumidification, and heating systems. Dr. Sabeh uses the psych chart to estimate the changes in enthalpy and moisture that occur throughout the production cycle on hourly, daily, and annual bases.

**GROW TIP:** Higher VPD levels require more energy to cool and dehumidify the air.

With knowledge of any two data points on the psych chart, Dr. Sabeh can determine all of the other atmospheric conditions, including the dew point temperature, the air's total moisture content, and even the density of the air. Calculating a change in the air's properties using data points on the psych chart yields valuable information for environmental management. For example, Dr. Sabeh might input the target setpoints for temperature and relative humidity during the photoperiod to calculate the amount of heat and moisture that needs to be removed via cooling and dehumidification, respectively, to achieve those setpoints.

**GROW TIP:** Refrigeration-based dehumidification often removes more heat than is required to control temperature and can overcool the room.

**FIGURE 6: QUICK REFERENCE CANNABIS VPD CHART**

| Temp °F | RELATIVE HUMIDITY | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100% | 95% | 90% | 85% | 80% | 75% | 70% | 65% | 60% | 55% | 50% | 45% | 40% | 35% |
| **87°** | 0.00 | 0.22 | 0.44 | 0.66 | 0.88 | 1.10 | 1.32 | 1.54 | 1.76 | 1.98 | 2.19 | 2.41 | 2.63 | 2.85 |
| **86°** | 0.00 | 0.21 | 0.42 | 0.64 | 0.85 | 1.06 | 1.27 | 1.48 | 1.70 | 1.91 | 2.12 | 2.33 | 2.55 | 2.76 |
| **85°** | 0.00 | 0.20 | 0.41 | 0.61 | 0.82 | 1.02 | 1.23 | 1.43 | 1.64 | 1.84 | 2.05 | 2.25 | 2.46 | 2.66 |
| **84°** | 0.00 | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.19 | 1.39 | 1.59 | 1.79 | 1.99 | 2.19 | 2.39 | 2.59 |
| **83°** | 0.00 | 0.19 | 0.38 | 0.58 | 0.77 | 0.96 | 1.15 | 1.35 | 1.54 | 1.73 | 1.92 | 2.12 | 2.31 | 2.50 |
| **82°** | 0.00 | 0.19 | 0.37 | 0.56 | 0.75 | 0.93 | 1.12 | 1.31 | 1.49 | 1.68 | 1.87 | 2.05 | 2.24 | 2.43 |
| **81°** | 0.00 | 0.18 | 0.36 | 0.54 | 0.72 | 0.90 | 1.08 | 1.26 | 1.44 | 1.62 | 1.80 | 1.98 | 2.16 | 2.34 |
| **80°** | 0.00 | 0.18 | 0.35 | 0.53 | 0.70 | 0.88 | 1.05 | 1.23 | 1.40 | 1.58 | 1.75 | 1.93 | 2.10 | 2.28 |
| **79°** | 0.00 | 0.17 | 0.34 | 0.51 | 0.68 | 0.85 | 1.01 | 1.18 | 1.35 | 1.52 | 1.69 | 1.86 | 2.03 | 2.20 |
| **78°** | 0.00 | 0.16 | 0.33 | 0.49 | 0.66 | 0.82 | 0.98 | 1.15 | 1.31 | 1.48 | 1.64 | 1.81 | 1.97 | 2.13 |
| **77°** | 0.00 | 0.16 | 0.32 | 0.48 | 0.63 | 0.79 | 0.95 | 1.11 | 1.27 | 1.43 | 1.58 | 1.74 | 1.90 | 2.06 |
| **76°** | 0.00 | 0.15 | 0.31 | 0.46 | 0.61 | 0.76 | 0.92 | 1.07 | 1.22 | 1.38 | 1.53 | 1.68 | 1.83 | 1.99 |
| **75°** | 0.00 | 0.15 | 0.30 | 0.44 | 0.59 | 0.74 | 0.89 | 1.04 | 1.19 | 1.33 | 1.48 | 1.63 | 1.78 | 1.93 |
| **74°** | 0.00 | 0.14 | 0.29 | 0.43 | 0.57 | 0.71 | 0.86 | 1.00 | 1.14 | 1.29 | 1.43 | 1.57 | 1.72 | 1.86 |
| **73°** | 0.00 | 0.14 | 0.28 | 0.42 | 0.56 | 0.69 | 0.83 | 0.97 | 1.11 | 1.25 | 1.39 | 1.53 | 1.67 | 1.80 |
| **72°** | 0.00 | 0.13 | 0.27 | 0.40 | 0.54 | 0.67 | 0.80 | 0.94 | 1.07 | 1.20 | 1.34 | 1.47 | 1.61 | 1.75 |
| **71°** | 0.00 | 0.13 | 0.26 | 0.39 | 0.52 | 0.65 | 0.78 | 0.91 | 1.04 | 1.17 | 1.30 | 1.43 | 1.56 | 1.69 |
| **70°** | 0.00 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 0.75 | 0.88 | 1.00 | 1.13 | 1.25 | 1.38 | 1.50 | 1.63 |
| **69°** | 0.00 | 0.12 | 0.24 | 0.36 | 0.49 | 0.61 | 0.73 | 0.85 | 0.97 | 1.09 | 1.21 | 1.33 | 1.46 | 1.58 |
| **68°** | 0.00 | 0.12 | 0.23 | 0.35 | 0.47 | 0.58 | 0.70 | 0.82 | 0.94 | 1.05 | 1.17 | 1.29 | 1.40 | 1.52 |
| **67°** | 0.00 | 0.11 | 0.23 | 0.34 | 0.45 | 0.56 | 0.68 | 0.79 | 0.90 | 1.01 | 1.13 | 1.24 | 1.35 | 1.46 |
| **66°** | 0.00 | 0.11 | 0.22 | 0.33 | 0.44 | 0.55 | 0.65 | 0.76 | 0.87 | 0.98 | 1.09 | 1.20 | 1.31 | 1.42 |
| **65°** | 0.00 | 0.11 | 0.21 | 0.32 | 0.42 | 0.53 | 0.63 | 0.74 | 0.84 | 0.95 | 1.05 | 1.16 | 1.26 | 1.37 |
| Vegetative, VPD = 0.80 to 0.95 | | | | | Flowering, VPD = 0.96 to 1.15 | | | | | Stress, VPD = 1.16 to 1.35 | | | | |

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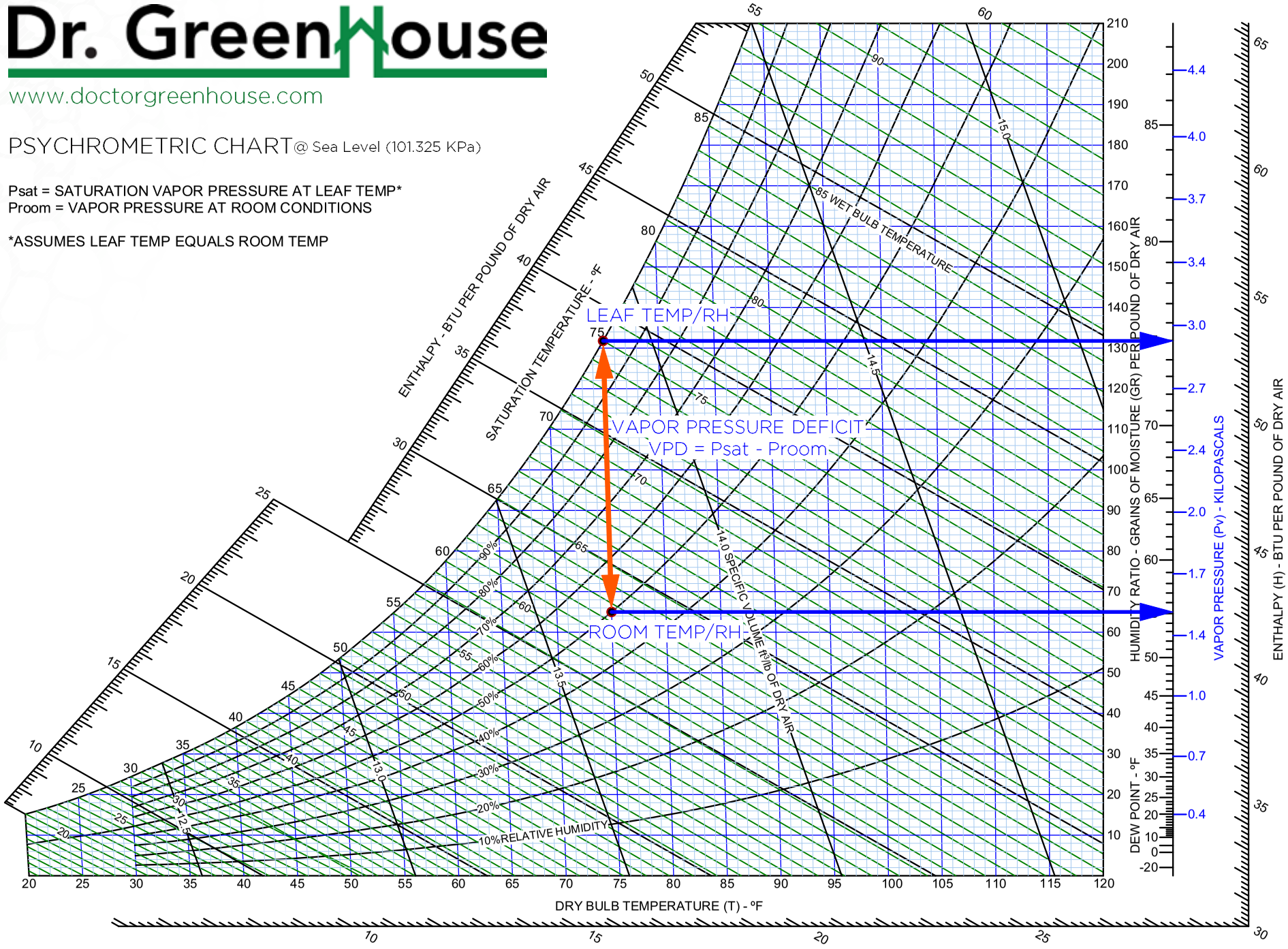
# PSYCHROMETRIC CHART @ Sea Level (101.325 KPa)

Psat = SATURATION VAPOR PRESSURE AT LEAF TEMP*
Proom = VAPOR PRESSURE AT ROOM CONDITIONS

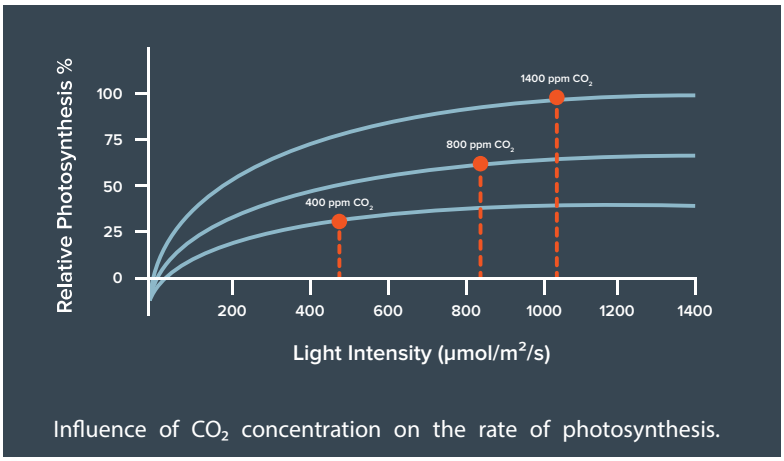
*ASSUMES LEAF TEMP EQUALS ROOM TEMP



# $CO_2$ ENRICHMENT

Optimum $CO_2$ levels for growing under high-PPFD lights often range from 400-1,400 ppm, and depend on the plant's growth stage, as well as the light intensity and air temperature. As plants grow throughout the production cycle, increasing light intensity will promote higher rates of photosynthesis, which is ideally supplemented by increasing $CO_2$ levels to enhance the photosynthesis process. At PPFD of ≥500 µmol/m²/s, we recommend $CO_2$ levels of ≥800 ppm [Figure 7].

**FIGURE 7**




Influence of $CO_2$ concentration on the rate of photosynthesis.

Temperature also plays an important role in accelerated gas exchange. High-PPFD light and high $CO_2$ concentrations must pair with higher temperatures to balance the transpiration rates associated with wide-open stomata. Dr. Sabeh notes that some cultivators may run 1,400 ppm/1,000 µmol/m²/s while keeping their rooms at 75 °F. The relatively low temperature limits the benefits of $CO_2$ enrichment and supplemented photons. In the reproductive phase of growth, temperatures as high as 84°F are recommended, and growers may find a 90° room is acceptable for some cultivars.

FIGURE 8: **RECOMMENDED $CO_2$ CONCENTRATION (PPM)**

| Species | Establishment | Vegetative | Reproductive |
|---|---|---|---|
| Cannabis | 400 | 400-800 | 800-1400 |
| Tomatoes | 400 | 400-800 | 700-1200 |
| Cucumbers | 400-600 | 400-600 | 800-1000 |
| Peppers | 400-600 | 400-800 | 800-1000 |

# NUTRIENTS

While plant nutrition is not something growers intuitively think of when retrofitting a facility, it is important to remember plant transpiration rates increase under high intensity lighting strategies. Allison Justice, a cultivation consultant and owner of the Hemp Mine, is a grower who closely monitors and experiments with nutrient uptake and is very familiar with how to best leverage high-intensity LEDs. Here, Justice provides practical advice on how to adjust and develop new fertigation strategies.

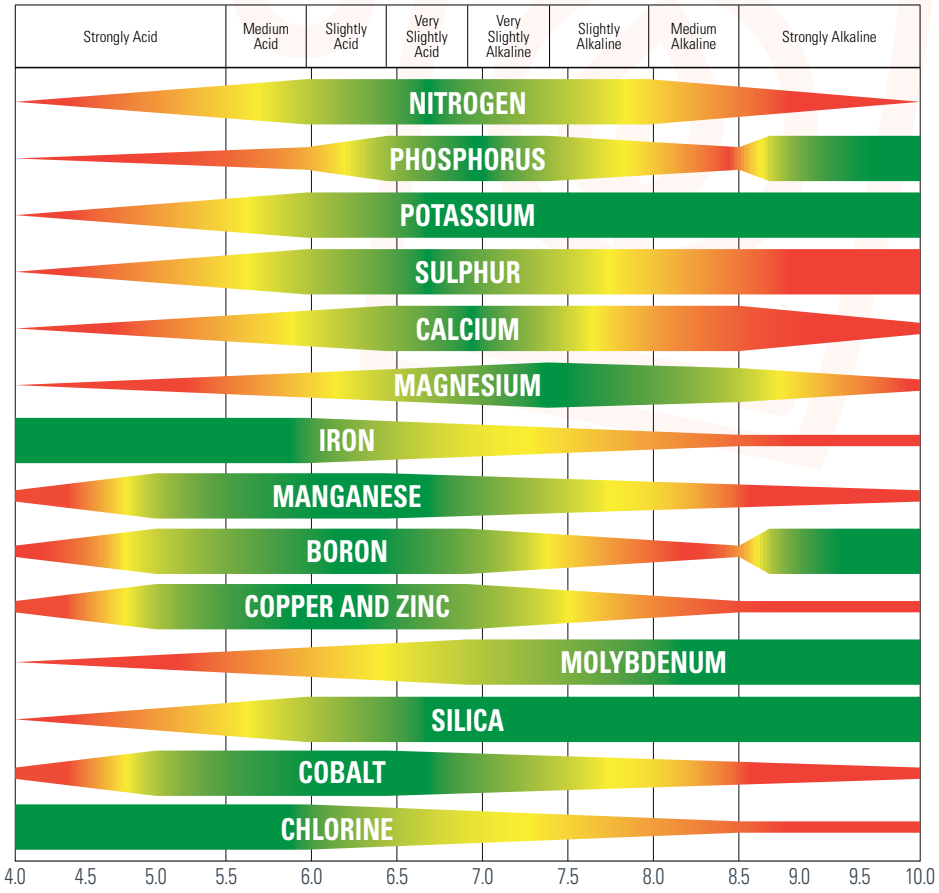
## NUTRIENT UPTAKE AND SOLUBILITY

Sixteen mineral nutrients are essential for cannabis to thrive [Figure 9] — as well as light, carbon dioxide and water. However, delivering those nutrients to the root zone in their proper quantities — while maintaining bioavailability — can be a challenge. Justice notes that most nutrient difficulties arise because of pH instability and antagonistic nutrient combinations.

## BALANCING PH

As cultivators know, pH is critical to nutrient solubility and uptake. The wrong pH levels can lead to deficiencies and toxicities — even when the nutrient concentrations are appropriate. If pH levels are low, the solubility of micronutrients increases, and their increased availability can cause phytotoxicity. Alternately, when pH increases, micronutrients — along with phosphorus — become less soluble and less available to plants for nutrient absorption. To raise the pH level, add hydrated lime or calcium carbonate; if the pH begins to climb, consider switching to acid-based fertilizers with ammoniacal nitrogen or injecting acid (phosphoric or sulfuric being common).

FIGURE 9




Nutrient availability increases or decreases in response to pH. A pH level of 5.8 — 6.2 is appropriate for cannabis. *Chlorine's nutrient availability is more dependent on form more than pH ranges.

**GROW TIP:** Know your starting materials! Justice recommends laboratory testing your water supply's nutrient profile and pH level. Similarly, when hydrating your growing media, test the pH of the runoff (leachate) to check if the media is acidic or alkaline.

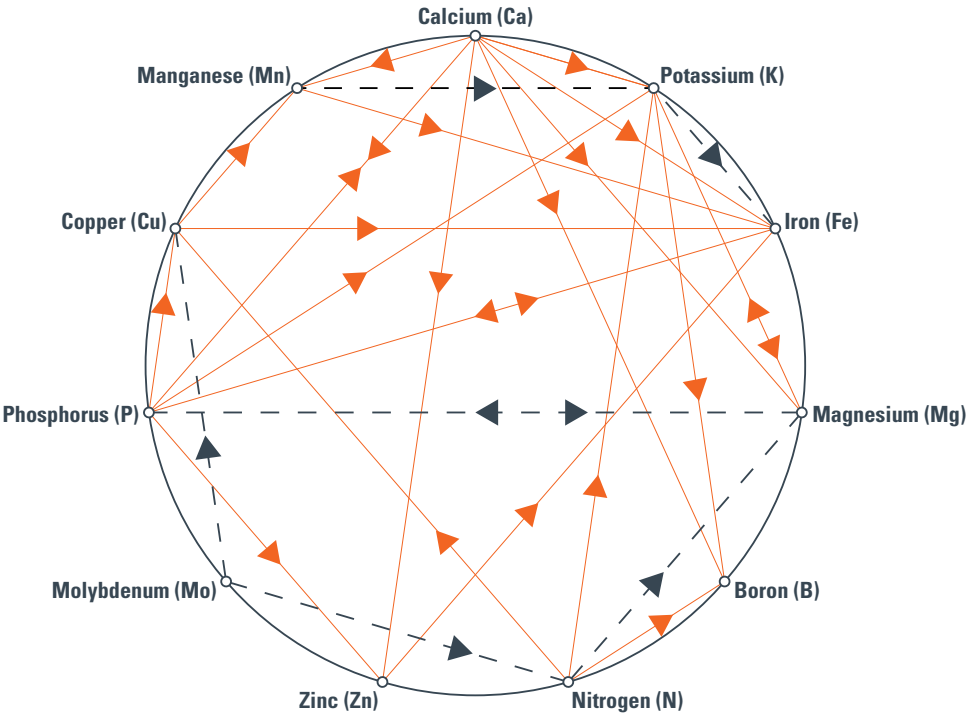
## NUTRIENT INTERACTIONS

How nutrients interact with one another matters. When combined, the nutrients in a fertilizer solution or growing medium antagonize or stimulate the plant's need for other nutrients. This action is based on how the plant uptakes nutrients. Because some nutrients are ionically similar, the plant cannot simultaneously uptake them both effectively. A common example would be calcium and magnesium; calcium antagonizes magnesium availability. In other words, high calcium levels make magnesium less bioavailable.

To predict chemical antagonisms and maximize nutrient-use efficiency, agronomists reference Mulder's Chart [Figure 10]. The chart depicts how nutrients either antagonize or stimulate the need for one another based on their respective ionic states and concentrations.

FIGURE 10: **MULDER'S CHART OF NUTRIENT ANTAGONISM**

| **ANTAGONISM** → | **STIMULATION** → |
|---|---|
| Decreased availability of a nutrient to plant due to the action of another nutrient | High level of a nutrient increases the demand by the plant for another nutrient |




## FEEDING SCHEDULES

Some cultivators feed their crops intermittently, alternating between water and fertilizer solution. Others use fertilizer for every irrigation event. Those with the ability to inject fertilizer in-line choose constant liquid feeding (CLF). CLF provides continuous nutrients but at lower concentrations [Table 2]. As you transition to higher-PPFD lighting, your plants will transpire more, and their water uptake will increase. To compensate, schedule more irrigation events at lower fertilizer concentrations.

TABLE 2: **EC RANGES PER IRRIGATION TYPE**

| GROWTH STAGE | Mom | Prop | Veg | Flower |
|---|---|---|---|---|
| INTERMITTENT FEEDING | 2.0 | 0.7-1 | 2.0 | 2.5-30 |
| CONSTANT LIQUID FEED | 1.2-1.5; 1.8 | 0.6-1 | 1.2-1.8 | 1.8-2.2 |

# ELECTRICAL CONDUCTIVITY

An electrical conductivity (EC) meter reports the overall nutrient concentration of a solution based on how nutrients change the conductivity of water. EC monitoring should be performed regularly to monitor the fertilizer as well as the salt build up in the growing media. Careful EC monitoring is important because the plant's nutritional needs increase significantly with maturity. Over fertilizing can create an antagonistic environment [Table 1].

In addition to in-house nutrient monitoring daily, Justice recommends working with a laboratory for elemental tissue analysis. For proper analysis of nutrient change over time, sampling should always be performed on new fully expanded leaves. In addition, by sampling leaves throughout the canopy, cultivators know how -- or if -- nutrients are being translocated to new growth.

After prolonged fertigation or overfeeding at too-high concentrations, nutrients can build up in the growing substrate and cause plants to refuse nutrition. The effect is similar to that of imbalanced pH: nutrient lockout. Regularly measuring the EC and pH with the Pour Thru Method (as described below) will help you make informed corrections.

**GROW TIP:** Many growers use parts-per-million meters (ppm meters) to gauge their nutrient concentrations. However, ppm meters base their measurements on electrical conductivity and apply a conversion factor to estimate the ppm level. Those conversion factors vary, depending on the model of the meter, so ppm meters often cause confusion. Fluence recommends EC meters with a combined pH function.

## EC LEVELS AND LEACHATE TESTING
### (Pour Thru Method)

- **SATURATE THE GROWING MEDIA:** Choose several plants from each zone. Add irrigation until the growing media is saturated. Then, wait 30-45 minutes so that the solution can homogenize across the entire media.
- **ADD WATER TO THE GROWING MEDIA:** Place a deep saucer under the pot and add purified water to the growing media at the base of the stalk. Depending on the pot size 200-500 mL will be necessary to saturate the growing media.
- **COLLECT THE LEACHATE:** Ideally, 50mL of leachate will pour through the growing media, but 100 mL will also produce an accurate reading. Transfer the solution to a cup deep enough to submerge the probes of the pH/EC meter.
- **MEASURE AND ANALYZE THE LEACHATE:** Your properly calibrated meter will display the pH and EC values. At this time, you can measure how the leachate from the root zone compares to your fertilizer. Compare your results [Table 2].

**KEEP RECORDS:** Make sure to record your leachate testing and fertilizer EC. Entering the data into a spreadsheet makes graphing your results easy. This information helps you better understand your crop's needs and how the metabolisms of your chosen cultivars compare to one another.

# INTEGRATED PEST MANAGEMENT

Suzanne Wainwright-Evans, owner of Buglady Consulting, encourages clients to keep detailed records of pest activity and focus on the identification of pests. By stringently monitoring pest activity, cultivators gain critical insights into how, when, and why a pest population may reach infestation levels. Often, infestations occur at the same time each year, at the same production stage, or at the same area in the facility. Reviewing detailed scouting records from the past can stop problems like these before they have a chance to start.

Training your scouts is essential for a successful monitoring program. Scouts should be familiar with the visible symptoms of an infestation, species identification methods, facility-specific pest problems, and the best way to walk the facility. Labor invested into scouting is one of the best pest mitigation methods available, so make sure to schedule scouting liberally and train your scouts well. Allocate several hours for scouting once or twice per week, depending on your facility size and crop.

**GROW TIP:** Proper identification of pests is the most important part of the scouting process, since biological controls can be specific to the species. As a final measure, perform one final check to ensure pests are not already dead before application, in case other controls have already helped to remedy the situation.

**GROW TIP:** Full-spectrum LED lighting makes scouting more effective. LED fixtures with isolated, blue/red-dominant spectrums will reduce your scouts' ability to see insects and the symptoms of other pathologies.

## SCOUTS SHOULD BE EQUIPPED WITH:

- **Scouting report forms or scouting app**
- **Identification guide**
- **Colored survey flags**
- **Cameras / usb microscope**
- **Hands-free magnifiers or hand lens**
- **Washable lab coats and gloves**
- **Vials of alcohol and a small, clean paint brush**
- **Sticky cards**

Sticky cards are an important tool and, according to Wainwright-Evans, an underused one. The cards attract and trap adult insects for identification and counts. The grid on the cards makes counting the pests easy, and consistent use of the cards allows cultivators to assess the insect population sizes and the effectiveness of pest management treatments. Inspect and change sticky cards weekly.

To better identify pests, scouts should collect insects by collecting them from the plant surfaces with a small brush and placing them in vials of alcohol. Then, the horticulture extension at your state university can help identify the pest species and begin the process of finding a remedy. Using a USB camera, such as the Dino-Lite Microscope Camera, can help off-site consultants identify your problem.

A positive species identification helps Wainwright-Evans in the early stages of a consulting job — even before she arrives on site — and the history of sticky cards and well-kept records help inform her first steps in remediation. With this information, she helps her client decide how — or if — to respond. Treatment options depend on plant stage, pest population levels, presence of beneficials and local pesticide laws.

PHOTO COURTESY OF SUZANNE WAINWRIGHT-EVANS

## SANITATION AND PREVENTION

Physical and cultural controls are strategies for crop isolation and grow room sanitation. Together, they lay the preventative groundwork for integrated pest management by making the growing space inhospitable to pests and preventing their entry. Good environmental control — as described in the Environmental Control Section of the guide — is primary to cultural controls. The practices described below complement proper environmental conditions.

- **Employee Hygiene:** Human traffic introduces pests into the grow room. Since guests and employees are often home growers, or have visited other facilities, they may transport pests from their gardens into yours. In the ornamental industry (which cannabis cultivators are beginning to model) cultivation technicians abide by strict hand-washing rules and careful management of all items and personnel that enter a facility. Washable lab coats and nitrile gloves are highly recommended. These extra preventative measures are worth the effort and added overhead expense.
- **Quarantine:** New genetic materials, equipment and cultivation supplies always pose risk when entering the facility. Wainwright-Evans recommends the quarantine of all in-bound materials for 14 days. It is also helpful to dip cuttings in a solution of a state-approved compound — even for plants propagated from in-house genetics. Always check the label because dip rates are often lower than sprays rates. The easiest way to mitigate pests is to keep them out of the growing space to begin with, so a distinct quarantine room in a receiving area is advisable to ensure pests do not enter the main facility. Do not use storage areas as a quarantine area.
- **Antimicrobial Surfaces:** To prevent powdery mildew and fungus, all surfaces of the growing space should be non-porous and washable. Metal tables are preferable to wooden ones. Vinyl and polyethylene paneling are superior to gypsum board walls. For greenhouses, concrete floors are better than gravel floors, which are an attractive habitat for many types of pests.
- **Water Sources and Harborage Areas:** Remove debris and pruned leaves from the growing area as soon as possible. Ideally, the growing media would be the only moisture source in the area. Always remove standing water immediately.
- **Irrigation:** It is best to fertigate with purified water. Water purification systems — which may utilize reverse osmosis, peroxides, ultraviolet light or combinations thereof — limit the risk of bacteria and fungi. Many cultivators benefit from adjusting their irrigation plan, too. Often, reducing the amount of irrigant per feeding reduces pythium, fusarium and algae. When cleaning rooms between crops, be sure to clean drip emitters, pests like root aphids can hide on them.
- **Air Sanitation:** Well-suited air sanitation systems are very effective for limiting powdery mildew and botrytis. Depending on your HVAC system and the volume of your growing space, your environmental control designer will specify a MERV-rated filter that integrates into HVAC. The higher the MERV rating, the more effective the filter. MERV 8 filters effectively remove mold spores; MERV 14 filters trap particles as small as bacteria. Alternately, UV-C filters placed within the ducts of your HVAC system can destroy most microbes.

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In addition to our experts, Fluence would like to acknowledge contributions from Jack Bohannan, Aaron Fellabaum, Elyse Greenberg, Dr. David Hawley, Travis Higginbotham, Ryley Leech, Carlos Perez, Casey Rivero, Sean Sangster, George Wang, NCERA, NCIA, as well the presenters and attendees of PHOTOx Summit.

Additionally, this guide references papers and bodies of work from the horticultural scientific community, including Mulder et al. and Sterling et al.

TEAR HERE

# Dr. GreenHouse

www.doctorgreenhouse.com

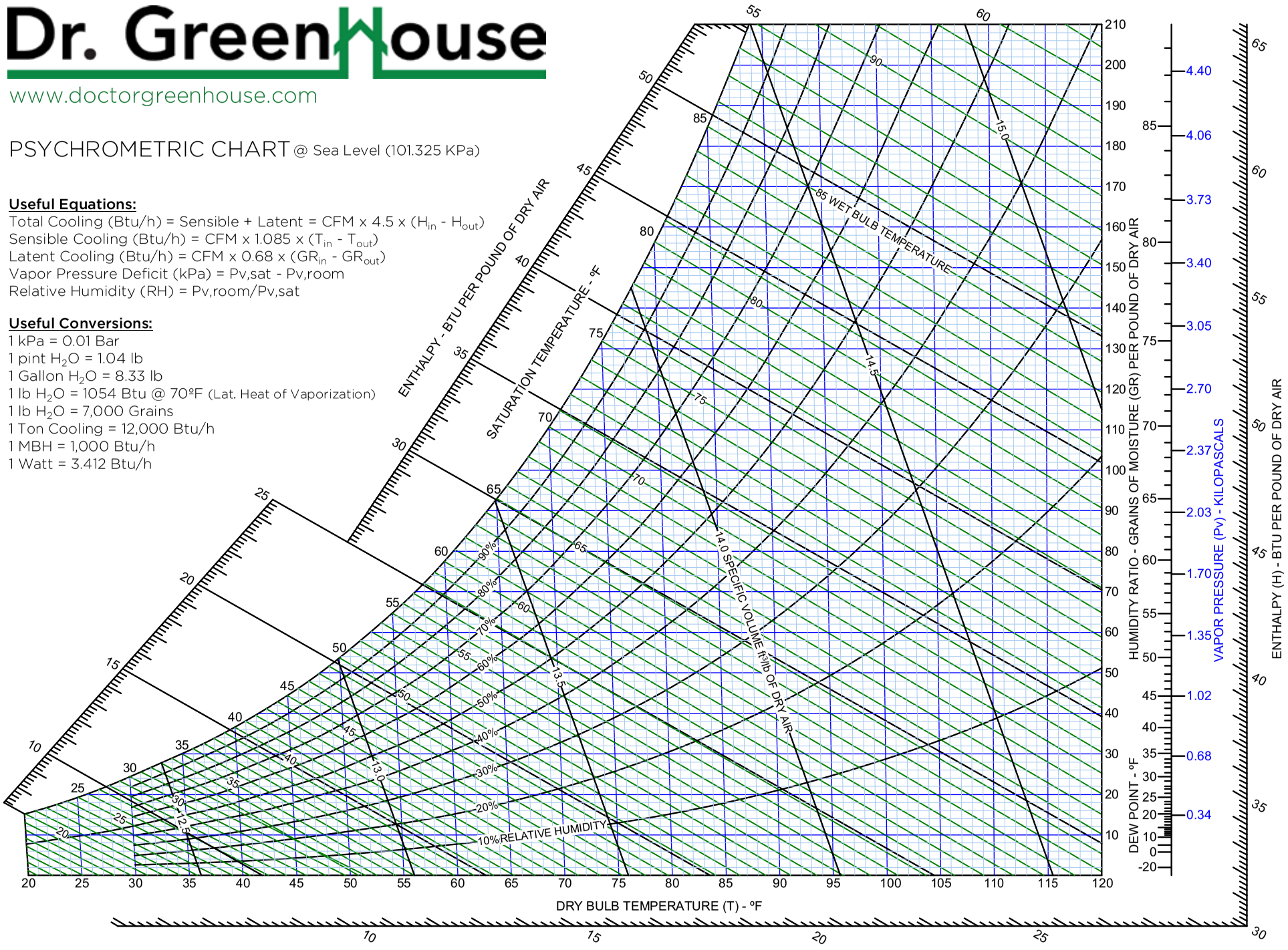
## PSYCHROMETRIC CHART @ Sea Level (101.325 KPa)

**Useful Equations:**

Total Cooling (Btu/h) = Sensible + Latent = CFM x 4.5 x ($H_{in}$ - $H_{out}$)
Sensible Cooling (Btu/h) = CFM x 1.085 x ($T_{in}$ - $T_{out}$)
Latent Cooling (Btu/h) = CFM x 0.68 x ($GR_{in}$ - $GR_{out}$)
Vapor Pressure Deficit (kPa) = Pv,sat - Pv,room
Relative Humidity (RH) = Pv,room/Pv,sat

**Useful Conversions:**

1 kPa = 0.01 Bar
1 pint $H_2O$ = 1.04 lb
1 Gallon $H_2O$ = 8.33 lb
1 lb $H_2O$ = 1054 Btu @ 70ºF (Lat. Heat of Vaporization)
1 lb $H_2O$ = 7,000 Grains
1 Ton Cooling = 12,000 Btu/h
1 MBH = 1,000 Btu/h
1 Watt = 3.412 Btu/h



## HOW TO CALCULATE VPD

1. Measure ambient dry-bulb temperature and humidity
2. Measure leaf temperature and assume leaf humidity is 100%
3. Plot both conditions on the psychrometric chart (see [Figure 6])
4. Find the vapor pressure of the two conditions
5. Subtract the difference between the vapor pressure of leaf and that of air

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