Crop Steering

A Comprehensive Guide by Growlink

Written by Marcus Baldinger and Kevin Crouch

Introduction

Recently, there has been an increase in conversations in the industry centered around crop steering to boost yields, save resources, and enhance trichome/terpene production. However, there are very few resources on crop steering available to cultivators. This resource guide was created to share our knowledge, while also helping to drive crop steering forward in the community.

Table of Contents

FOREWORD

By Kevin Crouch

Meet Kevin

@madtrichome

I grew up in South Sacramento, where I spent as much time as physically possible outdoors. Science and ecology were both topics I was always drawn to, so I decided to attend Humboldt State University where I received my B.S. in Wildlife Biology back in 2003. Humboldt started my journey cultivating cannabis, where it blossomed into a passion for growing all plants. In 2004, I fired up two lights and never looked back.

I had spent several years working for the California Dept of Fish and Wildlife (CDFW), before I ultimately decided to move onto an environmental consulting firm as a Project Biologist where I conducted marine and terrestrial wildlife surveys. I finished the 15-year tenure conducting environmental compliance and permitting for large oil and gas industry projects, all while conducting my own horticultural experiments. These horticultural experiments stemmed from the first cultivars I obtained, including Flo, Romulan, Blue Moonshine, Hindu Kush, Morning Star, and Sensi Star from the infamous Third Floor in Oakland. Those first strains blossomed into 100's of strains, multiple rooms, satellite grows, and dozens of breeding efforts. Throughout my cultivation career, I have used nearly all growing mediums and strategies, but have always preferred growing hydroponically.

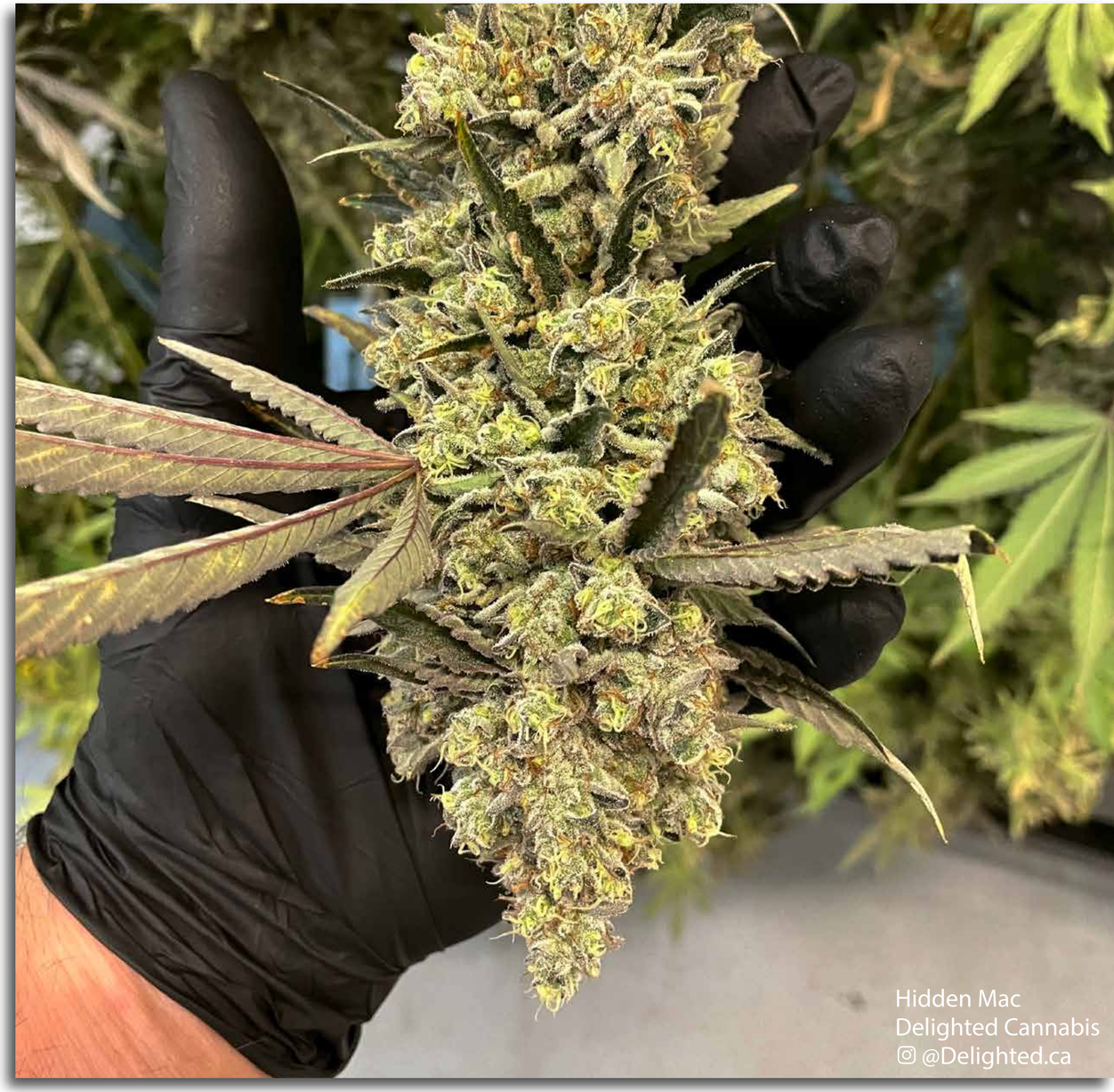
Seven years ago, I stumbled upon “dry farming” and after reading more, immediately began conducting side-by-side comparisons measuring runoff EC and approximate water content by weight. I found that despite EC being much higher, I did not see signs of nutrient burn, and flowers seemed to bulk faster. This general thought process was consistent with what I learned about osmotic pressure and water transport while attending Humboldt State. After years of consistent experimentation, I am still discovering new things and continuing to gather knowledge. In 2017 I met the Delighted team, and we began the design and build of a state-of-the-art indoor cultivation facility in Sacramento.

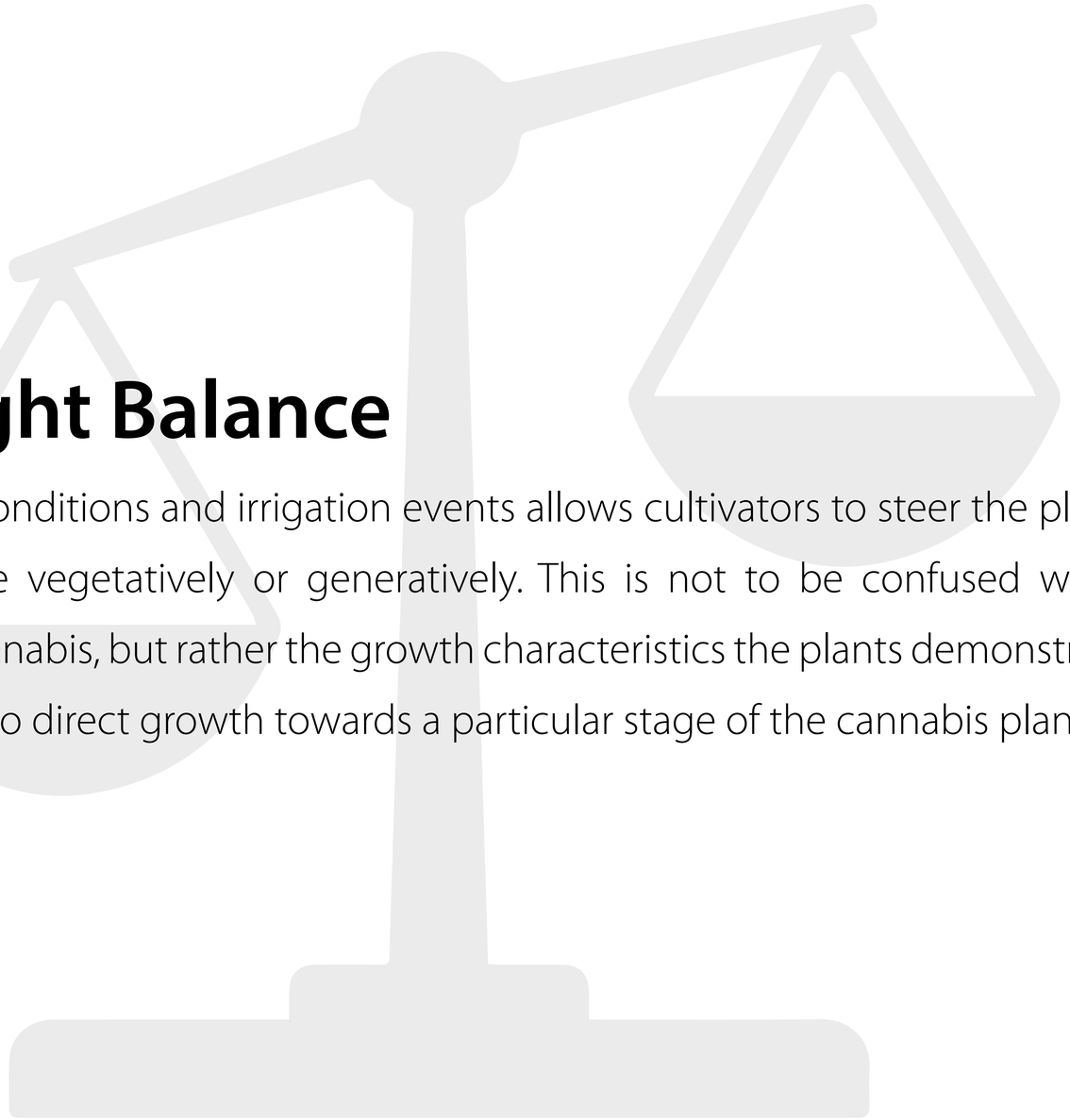
Fast forward to 2021… we have 10 double-stacked rooms with over 100 irrigation zones. Our facility has been utilizing the Growlink platform, which has assisted in controlling recipes from the fertigation skid, auto-filling batch tanks, monitoring and controlling room climate, light schedules, and dimming, as well as irrigation events. Growlink has allowed me to track water content and adjust irrigation events to accomplish specific crop steering goals. I worked directly with the Growlink team to help design and test their new Crop Steering Program in an effort to fully automate the process.

CANNABIS STEERING

What is Crop Steering?

Crop steering manipulates a plant's environment and root zone to influence metabolic/hormonal changes that inspire vigorous growth and greater yields. This is achieved by dialing in environmental conditions throughout different growth stages and managing irrigation events to mimic natural stressors the plant would encounter in nature. These changes can help influence a plant's growth patterns either vegetatively or generatively. Vegetative steering allows the plant to focus on the growth of leaves and stem structure while steering generatively focuses on flowering and reproduction.





Finding the Right Balance

Manipulating environmental conditions and irrigation events allows cultivators to steer the plants' metabolism and hormone balance either more vegetatively or generatively. This is not to be confused with the vegetative or flowering growth phases of cannabis, but rather the growth characteristics the plants demonstrate. Let's examine the differences and the right time to direct growth towards a particular stage of the cannabis plants' life cycle.

Steering Vegetatively

When you steer a plant vegetatively, you are essentially simulating perfect, stress-free conditions in nature. This signals to the plant that it's not in any danger of dying, and allows it to thrive, all while focusing on vigorous leaf growth and root output, as well as fortifying its stem structure to support the new growth. In order to achieve this, several adjustments should be made to both your irrigation strategy and environment. Ideally, warmer air temperatures paired with higher humidity will allow for optimum vapor pressure deficit (VPD) for vegetative growth. This is important because it reduces the transpiration needs of the plant, which lowers the osmotic pressure in the substrate, allowing for a higher uptake of nutrients.

Steering Vegetatively Cont...

Light intensity should remain low to moderate during this time as well. Too much light can cause stress and increase the need for transpiration, which would have an opposite effect on the osmotic pressure we are trying to achieve. Additionally, increasing the number of irrigation events or shots will help you achieve a higher volumetric water content (VWC) and lower your substrate's salinity or electrical conductivity (EC) by essentially flushing out the excess salt build up through runoff. It is important not to have too high of an EC in the substrate when steering vegetatively due to the lower osmotic pressure, since it allows the plant to uptake a higher percentage of available nutrients.

Vegetative Recommendations

Vegetative Climate Steering

Ambient Temperature	78˚ - 85˚ F
Relative Humidity (RH)	70% - 85%
Vapor Pressue Deficit (VPD)	0.6 - 1.1 kpa
CO_2	600 - 1000 ppm
Day/Night Temp. Differential	0˚ - 10˚ F

Vegetative Irrigation Steering

Shot Size	1% - 3% of substrate volume
Dry Back	1% - 10%
Substrate Temperature	74˚ - 78˚ F
Electrical Conductivity (EC)	2 - 4 dS/m
Target Water Content (VWC)	40% - 65% (Field capacity)
Ramp Up Irrigation Events	7 - 9

Steering Generatively

When you steer a plant generatively, you are simulating drought conditions found in nature. Drought conditions push the plant into survival mode, signaling a hormonal shift that allows it to focus heavily on reproduction. As a result, the plant will focus most of its energy on 'pre flower' bud site (calyx) creation and expansion to increase its chances of being pollinated. This, in turn, allows you to reap the benefits of a faster and more numerous bud set, which is the foundation of a bountiful harvest. Similar to steering vegetatively, you need to make several changes to your environment and your irrigation strategy to help steer the plant generatively.

Steering Generatively Cont...

To achieve optimum VPD levels for generative growth, both temperature and humidity should be lowered slightly. Light intensity should reach its peak to increase the need for transpiration which will ultimately cause a slight increase in osmotic pressure in the substrate. The lowering of temperature will aid in keeping leaf temps optimal under the increased light intensity. The increased rate of photosynthesis brought about by the increased light intensity will allow more photosynthates to be created, which can be used to develop flowers later on. Ultimately, the increase in osmotic stress causes the plant to take up more water than nutrients which, paired with fewer irrigation events at increased intervals, allows the substrates' soluble salt content (EC) to rise.

Generative Recommendations

Generative Climate Steering

Ambient Temperature	65˚ - 78˚ F
Relative Humidity (RH)	45% - 70%
Vapor Pressue Deficit (VPD)	1.0 - 1.5 kpa
CO_2	1000 - 1500 ppm
Day/Night Temp. Differential	0˚ - 10˚ F

Generative Irrigation Steering

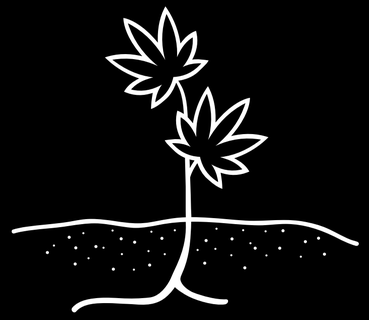
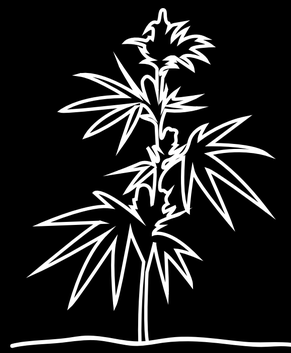
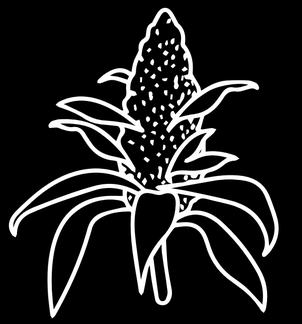
Shot Size	3% - 6% of substrate volume
Dry Back	15% - 30%
Substrate Temperature	74˚ - 78˚ F
Electrical Conductivity (EC)	5 - 12 dS/m
Target Water Content (VWC)	35% - 60% (Under field capacity)
Ramp Up Irrigation Events	5 - 7

PLANNING YOUR STRATEGY

Now that you know the basics of steering vegetatively and generatively, let’s determine the best time to steer one way or the other. Cannabis' life cycle usually lasts around 10-14 weeks in a commercial environment. With 2 to 4 of those weeks consisting of the vegetative stage and the remaining 8-10 weeks consisting of the flowering stage.

As a general guideline, you should look to steer more towards what is listed in the chart on page 19. However, it is just a general guideline, and you may need to adjust your steering to favor more of a middle ground between the two extremes based on how your specific genetics react. One crucial factor that is often overlooked is that while stress-based responses often give us the results we covet, they come at a cost. Steering generatively at any point during the growth cycle induces stress, inhibiting maximum potential growth and assimilate production. Short term, the benefits we see from this hormonal response, such as faster and more numerous bud sets and increased trichome and terpene production, outweigh the potential growth we are sacrificing; however, long-term stress exposure of any kind would be detrimental to yields.

Steering Strategy

Veg	Early Flower (Stretch, Pistils)	Mid Flower (Bulk)	Late Flower (Ripen)
			
Vegetative Growth	Generative Growth	Vegetative Growth	Generative Growth
2 - 4 weeks or longer	**3 weeks**	**3 - 5 weeks**	**2 weeks**
	8 -10 weeks		

Veg

We recommend steering vegetatively during the vegetative growth phase since the primary purpose is for the plant to establish a solid root foundation and stem structure. During this phase, plants produce as many leaves as possible to increase photosynthetic surface area to produce and store carbohydrates that will be used to produce flowers later on. Providing plenty of water by increasing the target VWC% and total irrigation events will prevent the plant from signaling any drought stress-related hormonal/metabolic responses, thus allowing vigorous growth to occur. The lowering of the substrate EC that follows, paired with decreasing VPD and light intensity will lower the osmotic pressure in the substrate, allowing the plant to uptake more nutrients without the risk of experiencing nutrient burn.

Early Flower

We recommend steering generatively during the early flower (stretch) phase, as this allows the plant to put its energy towards forming 'pre flower' bud sites (calyxes), increasing its chances of being pollinated. This helps reduce "stretch" and nodal spacing in many varieties, allowing for more even light penetration to colas that would typically be buried in the canopy. Decreasing overall substrate VWC% and irrigation events during this time will signal a drought stress-induced hormonal/metabolic shift in the plant, allowing for focus on reproduction. The overall increase in VPD and light intensity, will lead to an increase in osmotic pressure in the substrate. This further adds to the stress triggering this hormonal shift while also preventing the plant from being burned by the excess nutrients available.

Mid Flower

We recommend steering vegetatively during the mid flower (bulk) phase to help rebalance the stress hormones that the plant accumulated during the early flower phase. Doing so will signal the plant to change its focus from survival back to vigorous growth again. This shift will allow the newly established colas to be nurtured, while decreasing the chance of stress-related herming from occurring. The plant's primary goal is to be pollinated; thus, it will continually produce calyxes containing the pistils needed to grab pollen. This stacking, in an attempt to outreach its pistils further is what forms the dense colas we all love. Steering vegetatively during this time will help decrease the osmotic pressure in the substrate, allowing a higher percentage of nutrients to be uptaken by the plant, aiding in the formation of more calyxes.

Late Flower

We recommend shifting steering more generatively again during the late flower (ripening) phase as most of the bud weight has already been packed on, and most of the pistils have begun to die off and change color. At this point, inducing stress can aid in the ripening properties that growers tend to look for, such as increasing terpenes and trichomes and decreasing leaf production. The specific stressors we are looking for here are drier substrate conditions, decreases in temperature and humidity, and an increase in UV light exposure.

Late Flower Cont...

The creation of a mild drought scenario will signal the plant to go back into survival mode, which will lead to decreased leaf production. Decreasing temperature and humidity will stimulate a natural hormonal and metabolic response similar to a cooler fall climate. Daytime temperatures should stay below 78 in order to preserve terpenes, while nighttime temperatures as low as 60 can help to trigger the metabolic change we are looking for. Trichomes are the plant's way of protecting themselves from pests, dust, and UV light, so increasing UV exposure will stimulate a defense response and potentially increase trichome production. Most modern LEDs contain the full light spectrum, including UV, which can stimulate a similar increase in trichome and terpene production.

IRRIGATION STRATEGY

Breakdown of Phases

We're sure many of you have seen a chart like the one on page 27, but we'd like to further break it down to better explain what exactly is going on. There are typically 4 phases associated with crop steering.

Phase 0 (additional dryback)

Phase 1 (ramp up)

Phase 2 (maintenance)

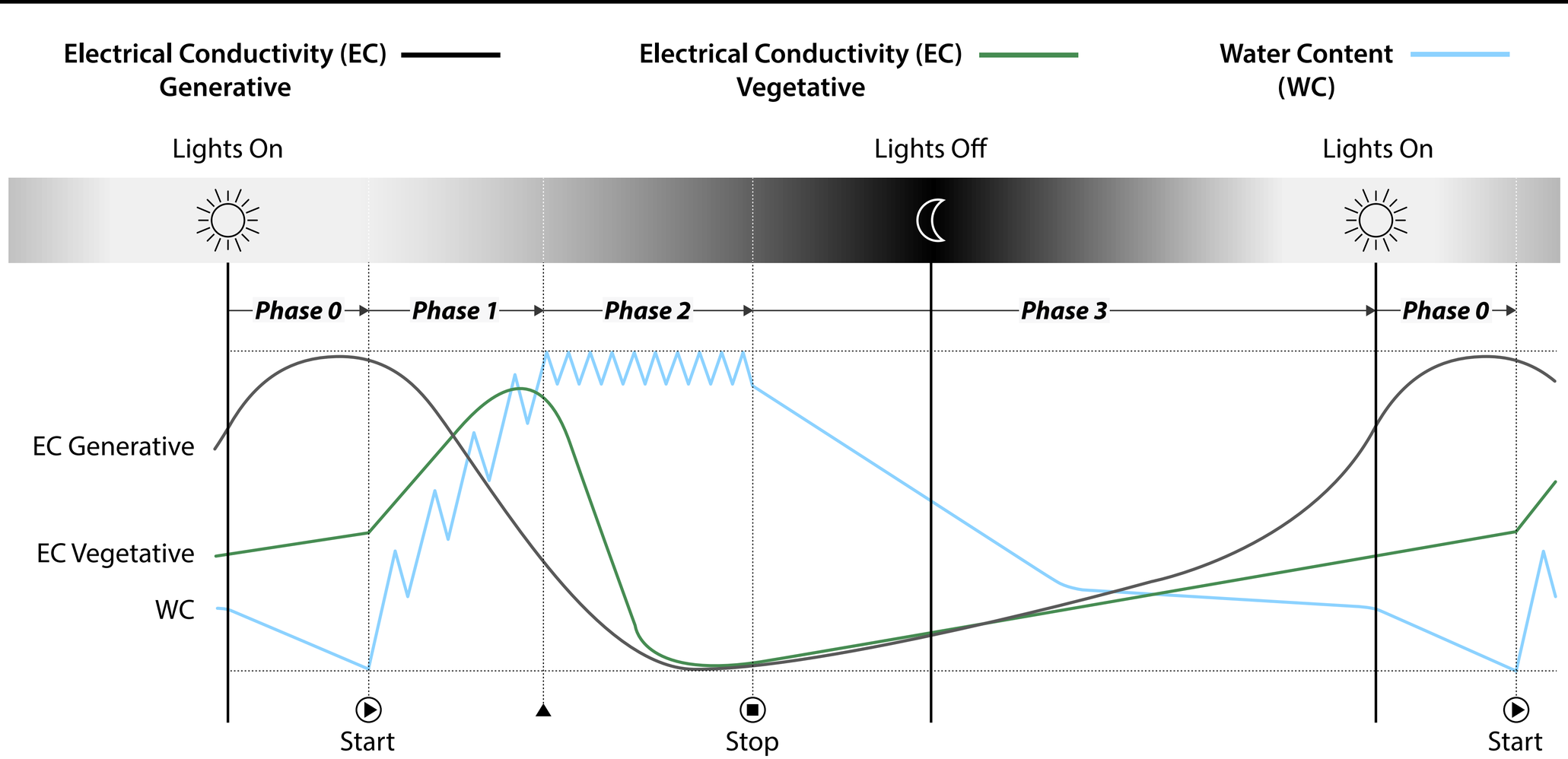
Phase 3 (overnight dryback)

Let's take a look at each one more closely.

Note:

EC is read as either pore EC or bulk EC. Pore EC measures the salinity of the available water content inside the substrate, whereas bulk EC measures the salinity of the substrate itself. Since plants can only take up nutrients in a soluble form, we default to pore EC measurements.

Irrigation Strategy



Phase Zero - Additional Dryback

Phase zero is the time period between the lights coming on, and the first irrigation event of the day. This is what we refer to as "additional dry back" in our Crop Steering Program. This additional dryback is especially important as it not only indicates when plants begin transpiring but it also helps to steer the plants metabolic balance for that day. Additional dry backs in this phase ranging from 1-3% are commonly used when steering vegetatively, while dry backs in the 4-6% range are often used when steering generatively.

EC Breakdown:

Generative:

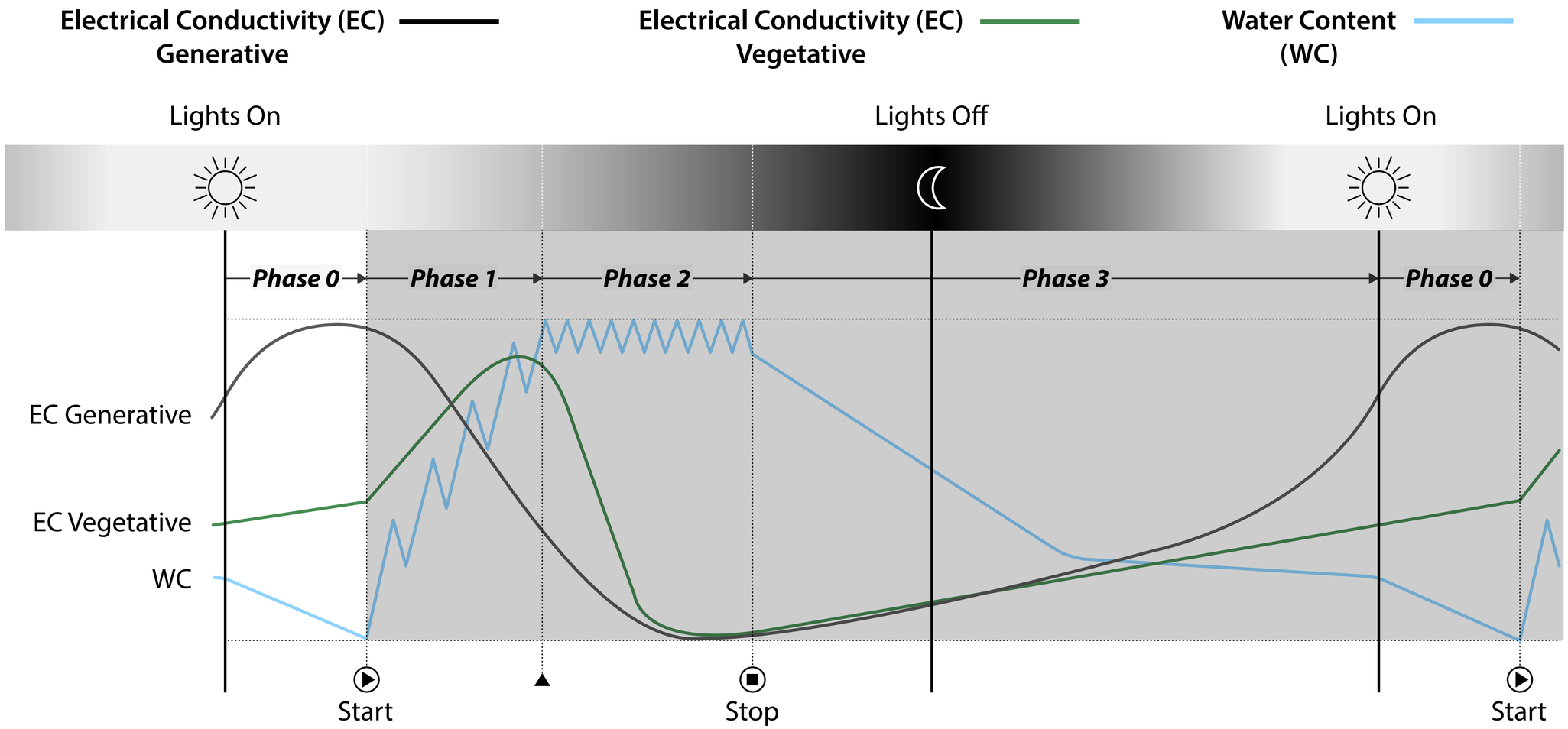
Substrate EC will often reach its peak during this phase as there is a substantial buildup of salts inside the substrate with very little moisture to dilute them.

EC Breakdown:

Vegetative:

Substrate EC will often be slightly lower than the feed EC due to plants uptaking a large percentage of available nutrients.

Phase Zero - Additional Dryback



Phase One - Ramp Up

Phase One is defined as the time between the first irrigation event of the day and when the substrate reaches its maximum target VWC%, also known as the "Ramp Up" phase. It is important to gradually raise your VWC by using small irrigation events (shots) rather than dosing it all at once to prevent unwanted channeling. Water will always take the path of least resistance on its journey due to gravity, so flooding the substrate with more water than can be readily absorbed will result in excess runoff and less than optimum even water absorption.

EC Breakdown:

Generative:

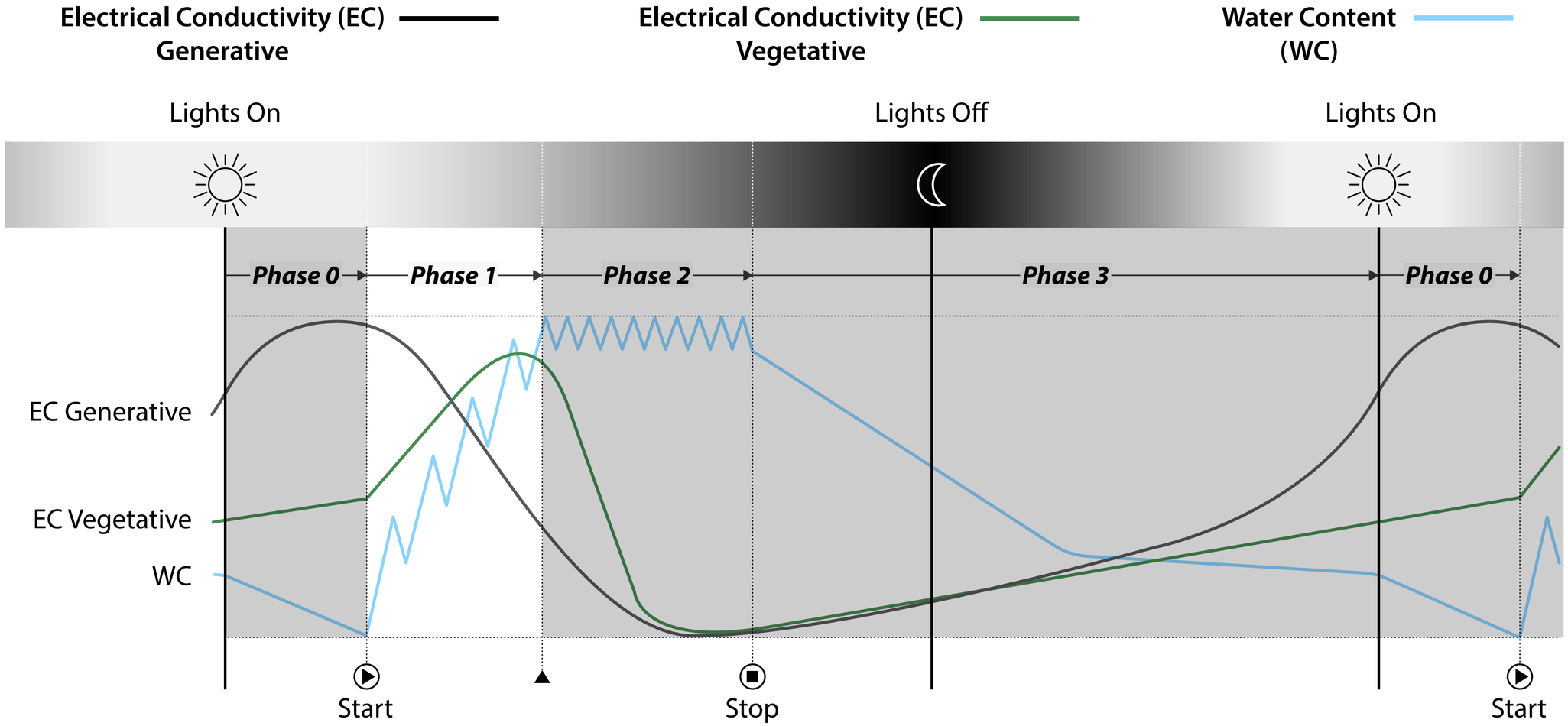
The increase in water volume should help dilute the built-up salts in the substrate, lowering the pore EC reading.

EC Breakdown:

Vegetative:

Substrate EC should begin to rise to or above your feed EC depending on the amount of salt buildup present.

Phase One - Ramp Up



Phase Two - Maintenance

Phase two, also known as the "Maintenance Phase," is the time between when the substrate reaches its maximum VWC% and the last irrigation event of the day. This phase is used to adjust the EC in your substrate by using smaller or larger dry backs in between shots. During this phase, your dryback % will also equal your shot size to maintain the desired VWC%. Smaller, more frequent shots will allow for more runoff, which will help flush out the built-up salts in the substrate, lowering your EC. Conversely, larger, less frequent shots will decrease the chances of runoff, thus allowing you to stack your EC in the substrate. These EC changes often take several days to become apparent.

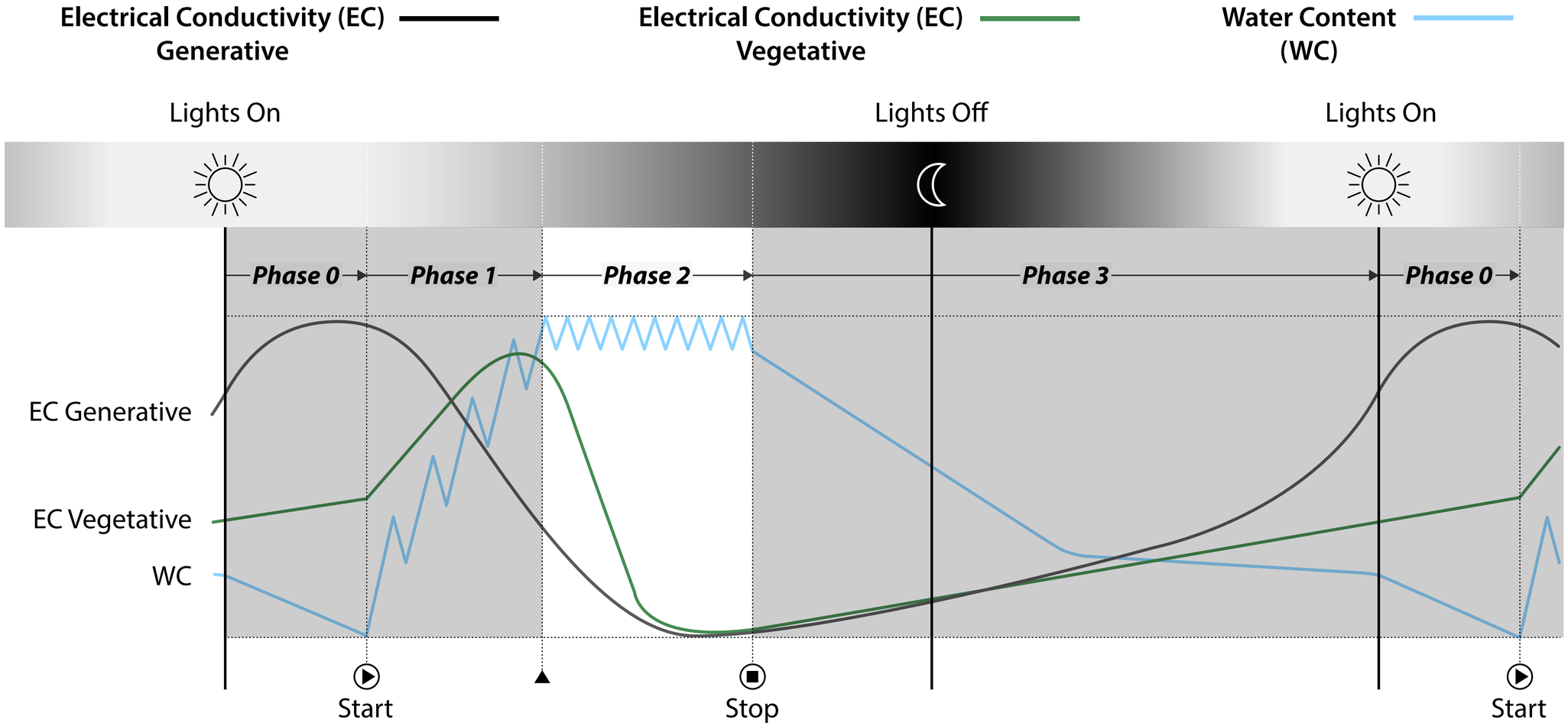
EC Breakdown:

Generatively: Substrate EC will continue to decline as it reaches its peak desired saturation, diluting built-up salts and potentially flushing some out with a lower EC solution. The target maintenance dry back setting largely determines the rate at which this occurs.

EC Breakdown:

Vegetative: Substrate EC should begin to decline as plants take up larger amounts of nutrients due to lower osmotic pressures and increased runoff typical of this phase.

Phase Two - Maintenance



Phase Three - Overnight Dryback

Phase three is known as the "Overnight dry Back" phase. It's defined as the time between the last irrigation event of the day, and when lights turn on the following day. During this time, the VWC% of your substrate will begin to quickly dry out as the plant continues to transpire during the remainder of your lights-on period and then shift to a more gradual drying pattern once the lights go out. This period is crucial as it exposes your plant to minor drought stress, triggering the desired hormonal response covered previously. It is common to end irrigation events several hours prior to lights turning off when steering generatively and push it closer to lights turning off when steering vegetatively.

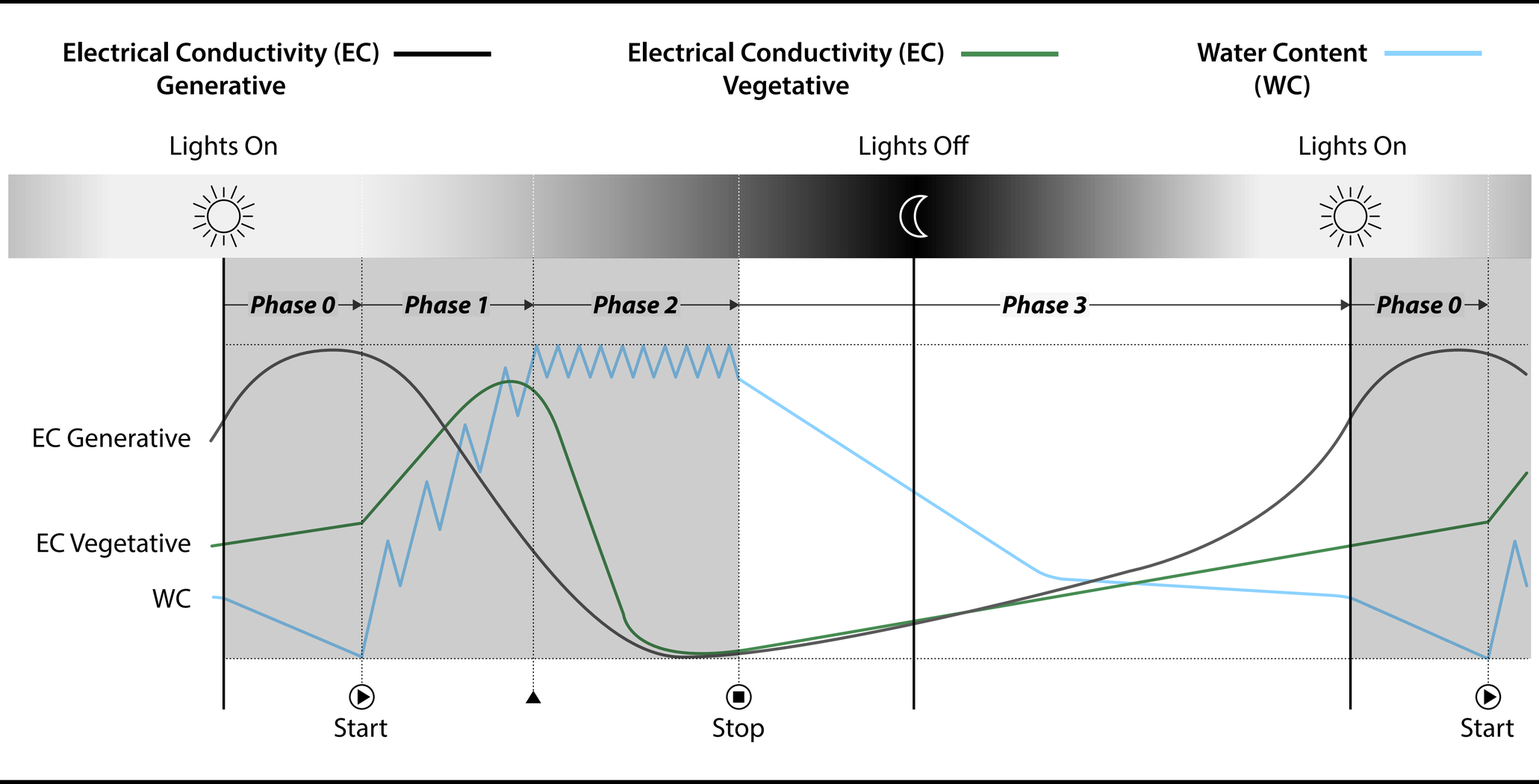
EC Breakdown:

Generative: Due to the increase in osmotic pressure in the root zone, more water than nutrients are uptaken, resulting in a build-up of salts over time. The less water available to dilute those salts, the higher the Pore EC reading will become.

EC Breakdown:

Vegetative: While the rootzone pressure isn't as high as when steering generatively, plants are still unable to uptake 100% of nutrients available, so salts will inevitably build-up, which paired with a decrease in water content to dilute them, will cause pore EC readings to rise slowly.

Phase Three - Overnight Dryback

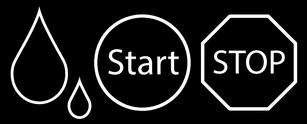


Crop Steering With Irrigation

Manages plant growth by adjusting environmental factors and/or irrigation to encourage a crop's desired outcome. Changing environmental conditions allows the influence of growth toward the desired growth stage, typically vegetative or generative.

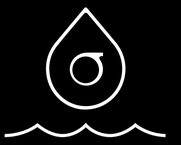
Water Content

Temperature



Feed Duration

Irrigation Frequency



EC

	Water Content	Temperature	Feed Duration	Irrigation Frequency	EC
Vegetative Growth	↑	↑	↓	↑	↓
Generative Growth	↓	↓	↑	↓	↑

ENVIRONMENTAL STRATEGY

Environmental Strategy

Irrigation, while extremely important, only makes up half of the recipe for success. Dialing in your environment is critical to achieving maximum results. Temperature, humidity, VPD, light intensity, and CO2 are the key variables we aim to keep balanced. These must be balanced to achieve optimum transpiration rates, assimilate production, and CO2 absorption. If any of these variables fall out of the optimum range, those variables will become the limiting factor, even if all others are at optimum levels.

Temperature

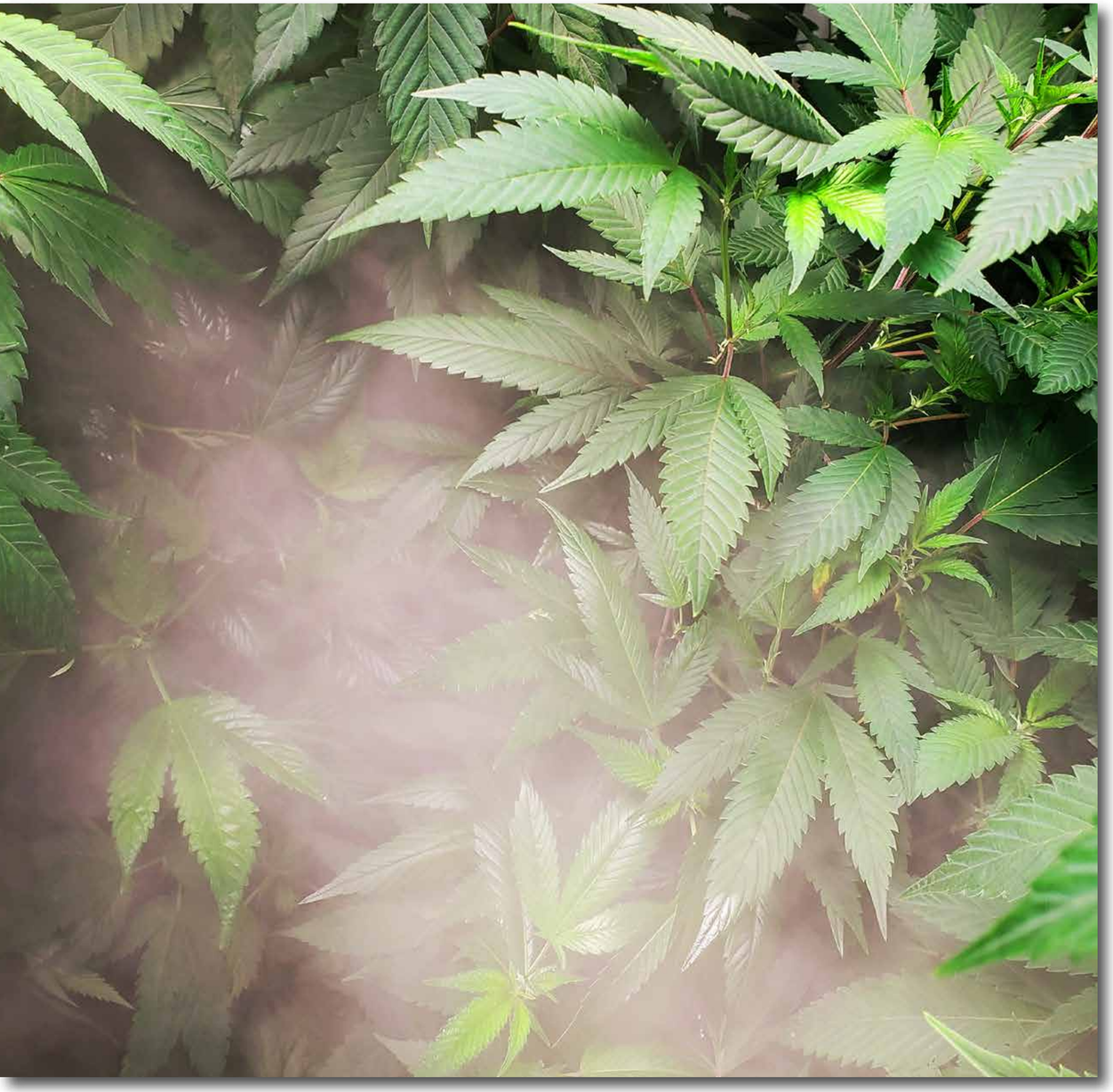
Air and leaf temperature while different, both impact the rate which plants grow and develop. Growth rates increase with temperature until an optimal temperature is reached. Optimal temperature for cannabis is in the upper 70's; however, when using supplemental CO2, the optimal range increases to the mid 80's. Air temperature can differ several degrees from leaf temperature depending on air circulation, light type/intensity, and humidity. The only way to determine leaf temperature is via thermal infrared cameras or infrared laser thermometers.

Temperature Cont...

When leaf temperatures are too high, plant development decreases, so it's imperative to lower temperature to prevent excess transpiration. When growing at warmer temperatures, adequate light intensity must be provided to prevent weak stem structure and increased internodal spacing. The difference between day and night temps is also an important factor in controlling plant morphology. Higher nighttime temps can reduce excess stretching, while lower nighttime temps can promote it.

Humidity

Plants remain active when there is a certain amount of evaporation occurring at any given time. It is ideal to ensure this evaporation rate does not halt at any point, as this can cause nutrient uptake issues. This is especially true with calcium, as it is immobile. Humidity plays a significant role in influencing these evaporation rates. When a plant is under intense lighting (high solar radiation), humidity must remain high to keep the stomata from closing prematurely in an effort to prevent dehydration.

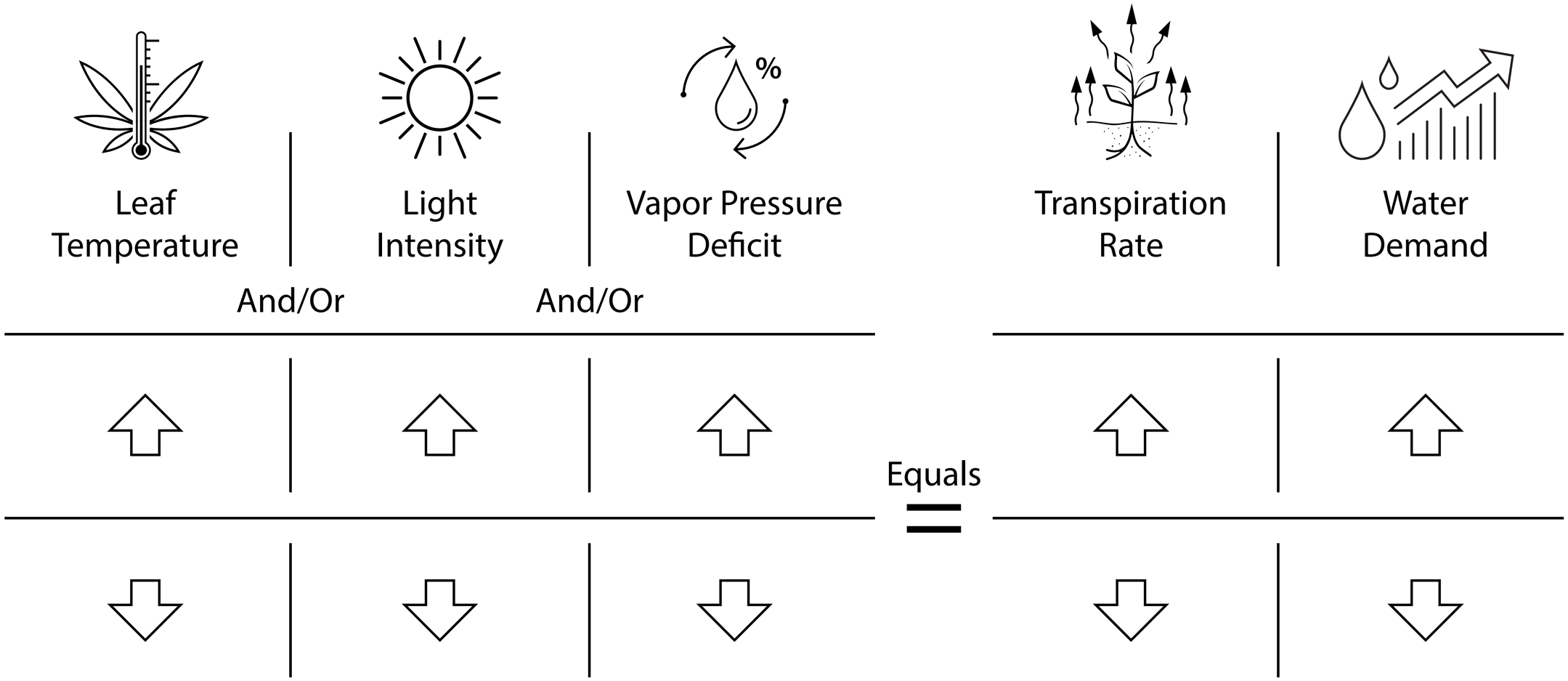


Humidity Cont...

Keeping stomata open during this time allows for maximum CO2 absorption as well. During the night cycle, while in the absence of solar radiation, evaporation is influenced primarily by air movement and humidity deficit. Without these, evaporation and uptake of nutrients will come to a halt. A lack of humidity deficit paired with poor air circulation and low calcium uptake often breeds the perfect environment for powdery mildew to occur.

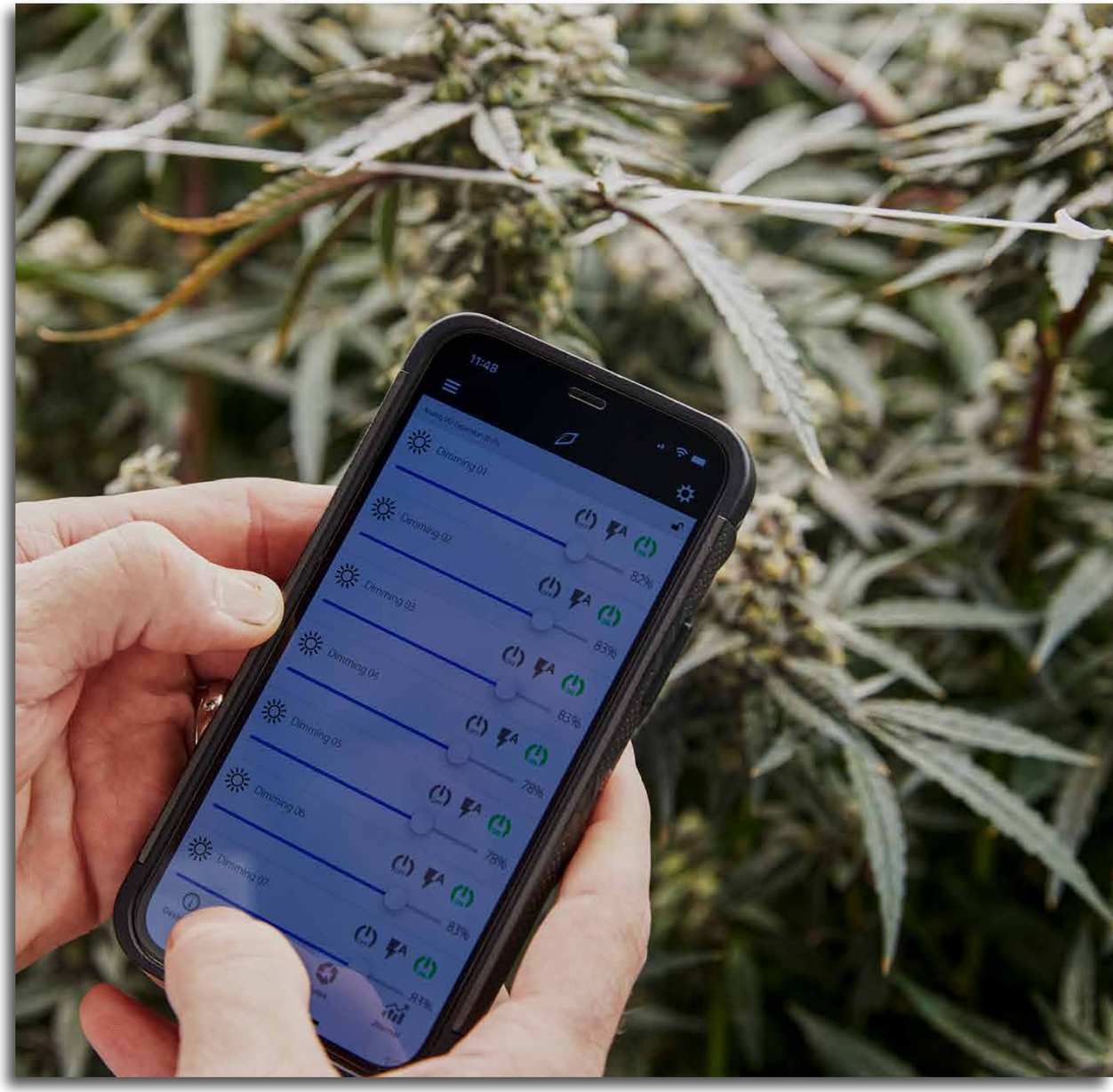
Transpiration Demand

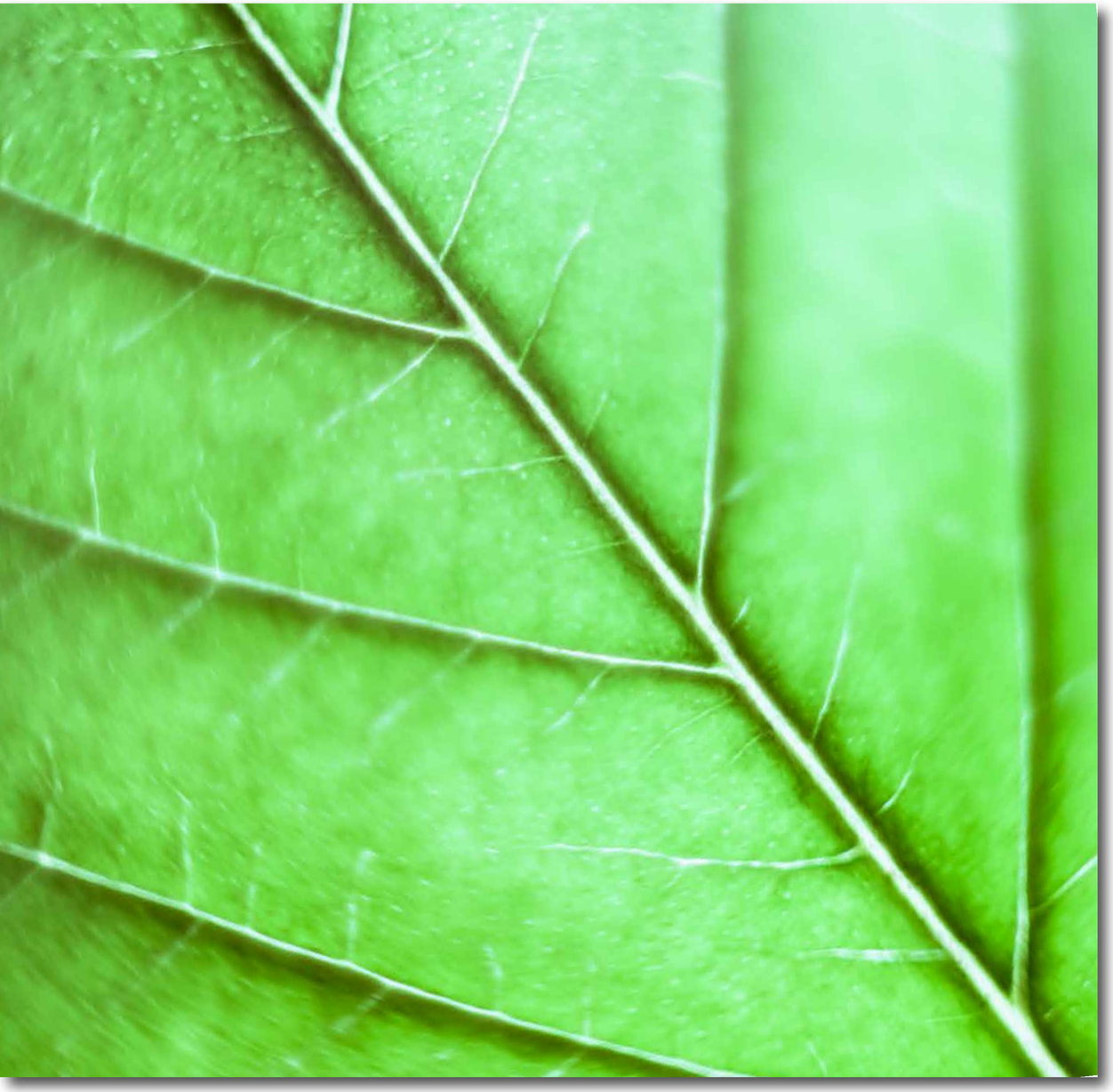
Increase or decrease in any of these variables will result in.....



Light Intensity

Commonly measured in Photosynthetic Photon Flux Density (PPFD), light intensity is measured to help predict how much radiation the plant is receiving in order to determine its transpiration rates. This is due to the majority of energy absorbed by the plant being discharged through evaporation. Higher PPFD values speed up photosynthetic rates until it plateaus, however, this point can be extended with proper CO_2 supplementation. It is crucial to avoid high PPFD during early growth stages to prevent light stress/chlorophyll pigment damage. PPFD values should be gradually increased as the plant matures and is capable of using the excess energy for increased photosynthesis.





Vapor Pressure Deficit

Vapor Pressure Deficit (VPD) is an important indicator of how open or closed the plant's stomata are, which helps us gauge how efficiently the plant can transpire and uptake CO2. Cultivators should try to keep their environment as stable as possible and within the optimal range indicated by the VPD chart on page 47.

Vapor Pressure Deficit Cont...

This rule has a few exceptions, such as early germination and establishment, as well as the late flowering phase (ripening). During the early establishment of seedlings and clones, kPa values of 0.3-0.5 are favorable as the need to transpire is not as crucial. During the late flower (ripening) phase, keeping humidity at or below 55% is crucial in avoiding fungal growth such as Botrytis from colonizing inside dense colas.

Vapor Pressure Deficit (kPa)

Key:

Optimal

Moderate

Sub-optimal

Temperature		Relative Humidity												
C°	F°	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%
15	59	.08	.17	.25	.34	.42	.51	.59	.68	.76	.85	.94	1.02	1.11
16	60.8	.09	.18	.28	.37	.46	.55	.64	.73	.82	.91	1.0	1.09	1.18
17	62.6	.10	.20	.29	.39	.49	.58	.68	.78	.88	.97	1.06	1.16	1.26
18	64.4	.10	.20	.31	.41	.51	.62	.72	.82	.93	1.03	1.13	1.24	1.34
19	66.2	.11	.22	.33	.44	.55	.66	.77	.88	.99	1.1	1.21	1.32	1.43
20	68	.12	.24	.35	.47	.59	.70	.82	.94	1.06	1.17	1.28	1.4	1.52
21	69.8	.12	.24	.37	.49	.62	.74	.86	.99	1.11	1.24	1.37	1.49	1.61
22	71.6	.13	.26	.39	.53	.66	.79	.92	1.05	1.19	1.32	1.45	1.58	1.72
23	73.4	.14	.28	.42	.56	.70	.85	.99	1.13	1.27	1.41	1.54	1.68	1.82
24	75.2	.15	.30	.45	.59	.74	.89	1.04	1.19	1.34	1.49	1.64	1.79	1.94
25	77	.16	.32	.48	.64	.80	.95	1.11	1.27	1.43	1.59	1.74	1.9	2.05
26	78.8	.17	.34	.51	.67	.84	1.01	1.18	1.34	1.51	1.68	1.84	2.01	2.18
27	80.6	.18	.35	.53	.71	.89	1.07	1.24	1.42	1.6	1.78	1.96	2.13	2.31
28	82.4	.19	.38	.57	.76	.95	1.14	1.33	1.51	1.7	1.89	2.07	2.26	2.45
29	84.2	.20	.40	.60	.80	1.0	1.2	1.4	1.6	1.8	2.0	2.21	2.41	2.61
30	86	.21	.42	.64	.85	1.06	1.27	1.48	1.7	1.91	2.12	2.33	2.54	2.75
31	87.8	.22	.45	.67	.90	1.12	1.34	1.57	1.79	2.02	2.24	2.46	2.69	2.91
32	89.6	.24	.47	.71	.95	1.19	1.42	1.66	1.9	2.13	2.37	2.61	2.84	3.08
33	91.4	.25	.50	.75	1.0	1.25	1.5	1.76	2.01	2.26	2.51	2.76	3.01	3.26
34	93.2	.27	.53	.80	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	3.18	3.45
35	95	.28	.56	.84	1.12	1.4	1.68	1.96	2.24	2.52	2.8	3.08	3.36	3.64

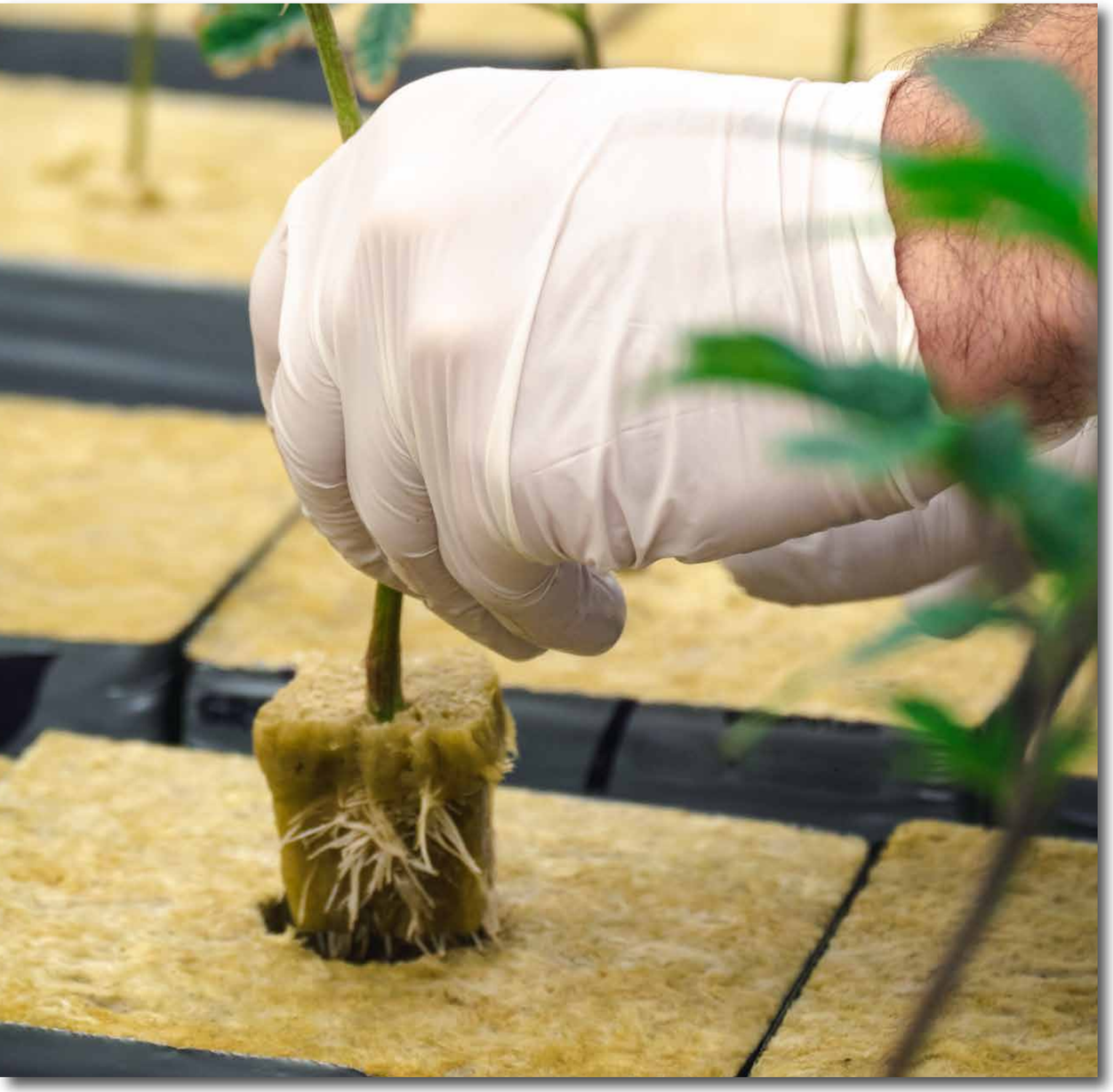
CO2

CO2 is a significant factor when maximizing plant growth potential. Without it, no matter how dialed in your environment is, or how many nutrients the plant has available, it will not perform to its maximum potential. Plants need light, water, and CO2 to produce assimilates (sugars), used as the building blocks for all plant growth. There are optimal ranges in which cannabis performs best. Higher temperatures, paired with higher humidity and light intensity, allow the plant to achieve maximum assimilate production and consumption. All of this translates to maximum overall growth potential.

GROWING TIPS

Transplanting

Generally, when transplanting into any substrate, it's ideal to pre-moisten the new substrate and allow substantial time to pass before beginning to irrigate regularly again. This practice encourages root growth into the new substrate as the plant searches for water. Roots tend to seek out lower EC environments, so charging your initial substrate with a higher EC than your new substrate will aid this process. Stacking Rockwool blocks is fundamentally no different; however, we often get asked questions regarding probe placement during this transition. We have found success in pre-soaking the new block before stacking the plant on top and moving the probe immediately into the new block.



Transplanting Cont...

This allows you to capture the starting VWC to compare the rate of change, which often serves as a good indicator of when sufficient root penetration has occurred. Once you notice the new block has dried out sufficiently, you may begin to irrigate again. Typically, during this process, the wicking properties of Rockwool will allow the initial block to pull up enough water from the new block to prevent wilting. If you notice wilting starting to occur, you can manually give a couple of small shots to keep the plant stable until its roots penetrate the substrate deep enough.

Pruning

There are differing opinions on pruning and whether it is beneficial. Whether to prune, when to do it, and to what extent varies depending on genetics and environment. Generally speaking, potential positives and negatives should be considered. A few potential benefits are better light penetration into the canopy in addition to the removal of 'sinks,' defined as leaf matter that would otherwise not receive adequate light and therefore solely consume assimilates. A few potential negatives to consider are that pruning leaves and branches reduces the plants' transpiration rate due to the reduction in the number of stomates, as well as the removal of stored carbohydrates that can no longer be utilized for energy or growth. The greater amount of leaf mass removed, will result in a larger reduction of transpiration possible. This will also appear as a slower dryback when monitoring substrate VWC. Pulling too many leaves may also result in plants producing a lower calyx-to-leaf ratio.

Probe Placement/Rotation

When it comes to probes, it is not ideal to "set and forget." When selecting which substrate to place your probe into, select one that accurately represents majority of the substrates around it. There will always be outliers that are wetter or drier than others. Catering to these outliers will prevent the bulk of your plants from reaching their ideal parameters. In order to achieve optimum results, you must periodically revisit whether the substrate you've selected still accurately represents the majority surrounding it. If it does not, then moving the probe to a substrate that does represent the majority is crucial. Never reuse previous probe holes when moving probes as it prevents solid contact between the probe and the substrate. To ensure the most accurate readings for probe placement, it is essential to insert the probe centered in the substrate and to keep it as horizontally level as possible.

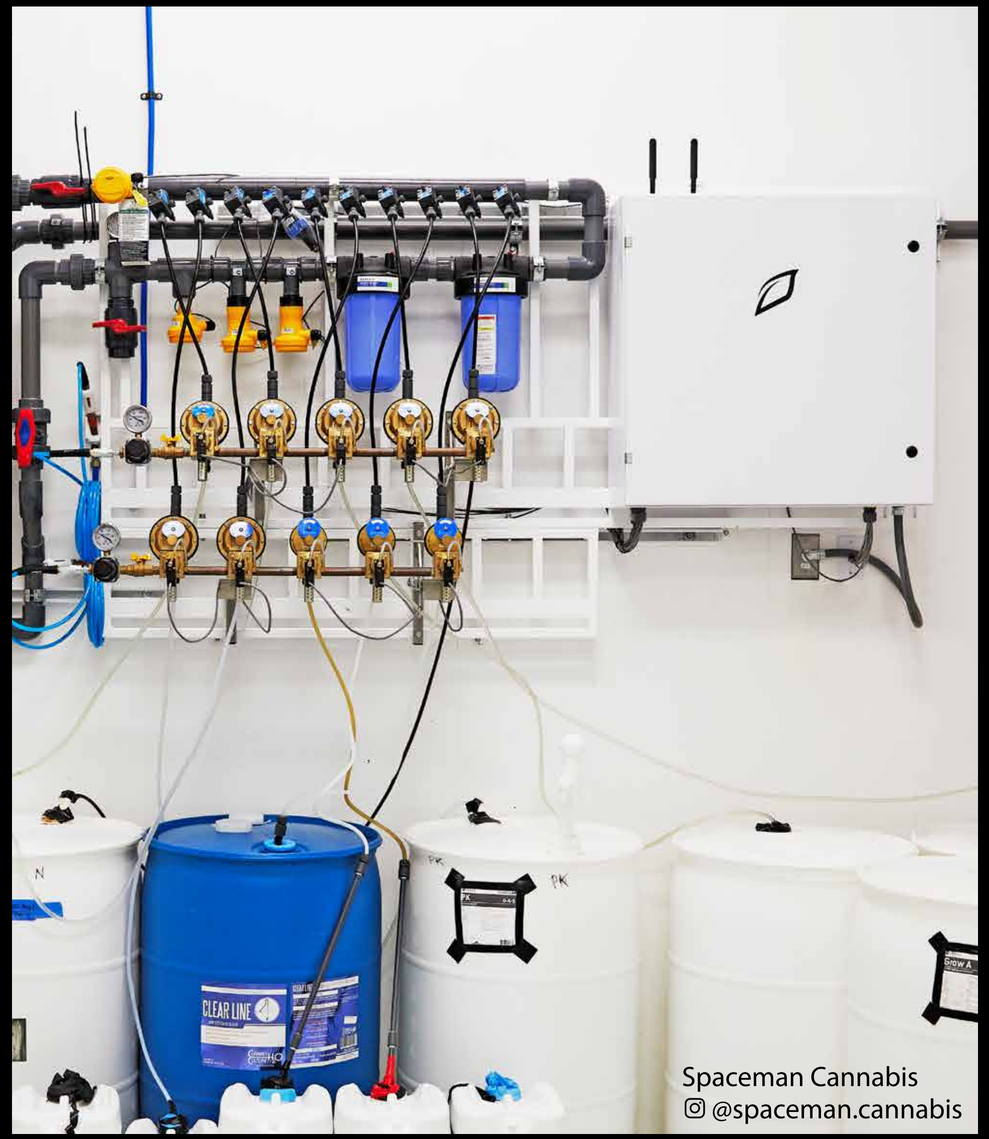
Flushing

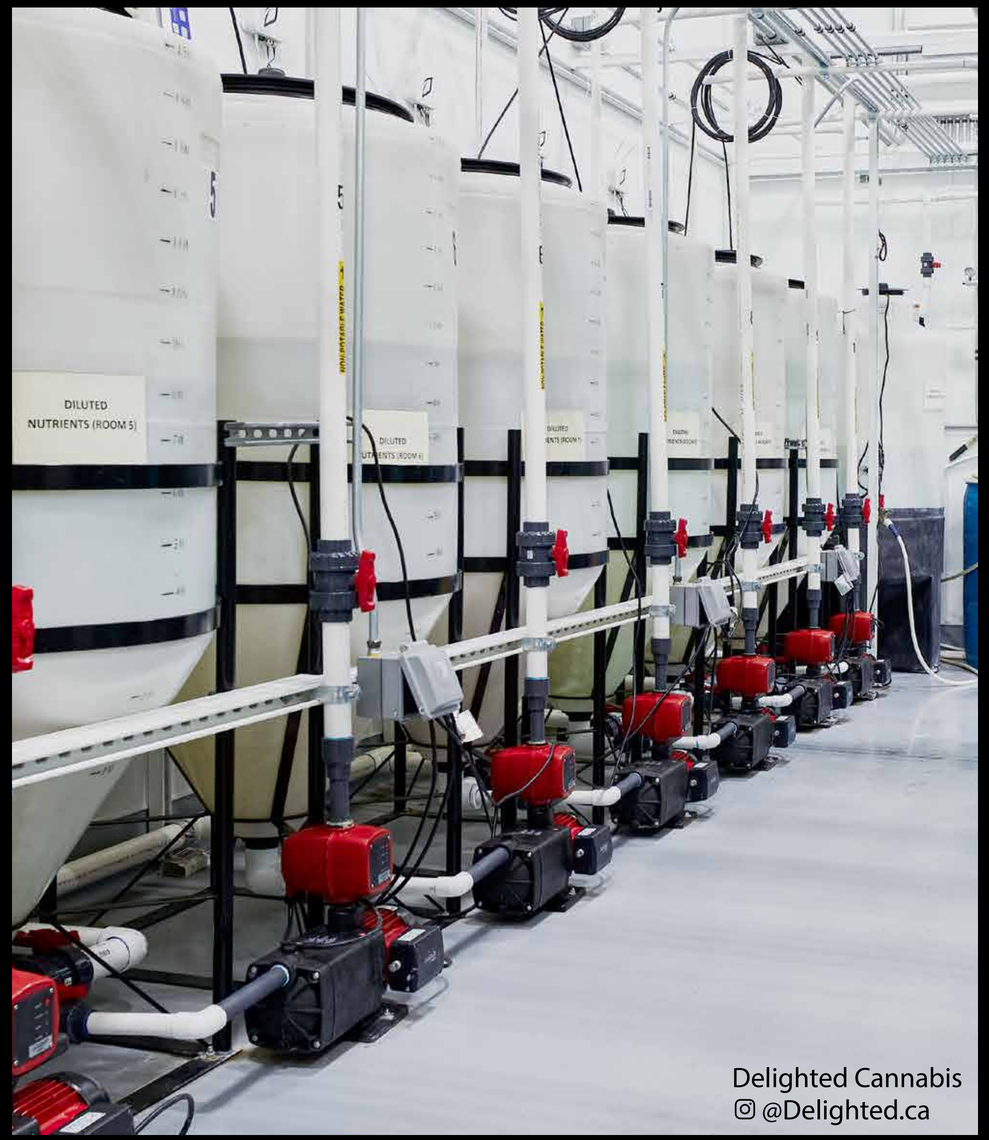
Like pruning, flushing is another topic that growers will have varied opinions on. What works great for some, might not work as well for others. One important thing to note is that if you are going to flush extensively, it is important not to remove calcium from your flush feed, as this can increase the chances of developing bud rot. We recommend simply lowering the EC of your feed rather than removing all nutrients from it.

IRRIGATION EQUIPMENT AND SETUP

Fertigation

Several fertigation systems on the market automate nutrient dosing, but none are as advanced or versatile as Growlink's. The software enables you to program custom nutrient recipes while monitoring vitals in real-time. It is capable of handling any flow rate and scaling dosing in real-time, making human errors a thing of the past. The software also makes real-time batch tank monitoring available, so you can observe fill level percentages and nutrient vitals from the same dashboard.





Batch Tanks

While the fertigation system is capable of direct injection feeding, due to the nature of our Crop Steering Program, it is almost impossible to guarantee the system will be available when a program calls for irrigation, especially in multi-room facilities. Having at least one batch tank per room with a dedicated pressure regulating pump ensures every row gets fed precisely when it needs it, regardless of how many programs and valves you have. Growlink allows for on-demand real-time water level readings using barometric pressure sensors. The sensors communicate with the fertigation system, ensuring each batch tank refills with whatever recipe you choose, and stops when you want it to, automatically.

Drip Emitters

There are many choices for drip emitters, ranging from a fraction of a gallon per hour to several gallons per hour. While many of these have an optimal use case in the right scenario, we have found that (0.5 gph to 1 gph) work best when crop steering. The is because our goal is to slowly and evenly saturate the substrate to prevent excess channeling from occurring since our substrates are often on the drier end of the spectrum. Both Rockwool and coco have a point of no return when it comes to dryness, meaning once they get too dry, they exhibit extremely hydrophobic properties.

TDR

TDR stands for "Time-Domain Reflectometry" and is a far superior technology for measuring water content. The TDR sensor works by creating a high-resolution image by sending a waveform into the substrate and measuring the returning reflections of the waveform. The image is then analyzed to determine the round-trip propagation time between the incident wave and the first reflected wave. The substrate permittivity can then be calculated, along with the water content, at a much higher resolution and accuracy over a capacitance-based sensor.

TDR Cont...

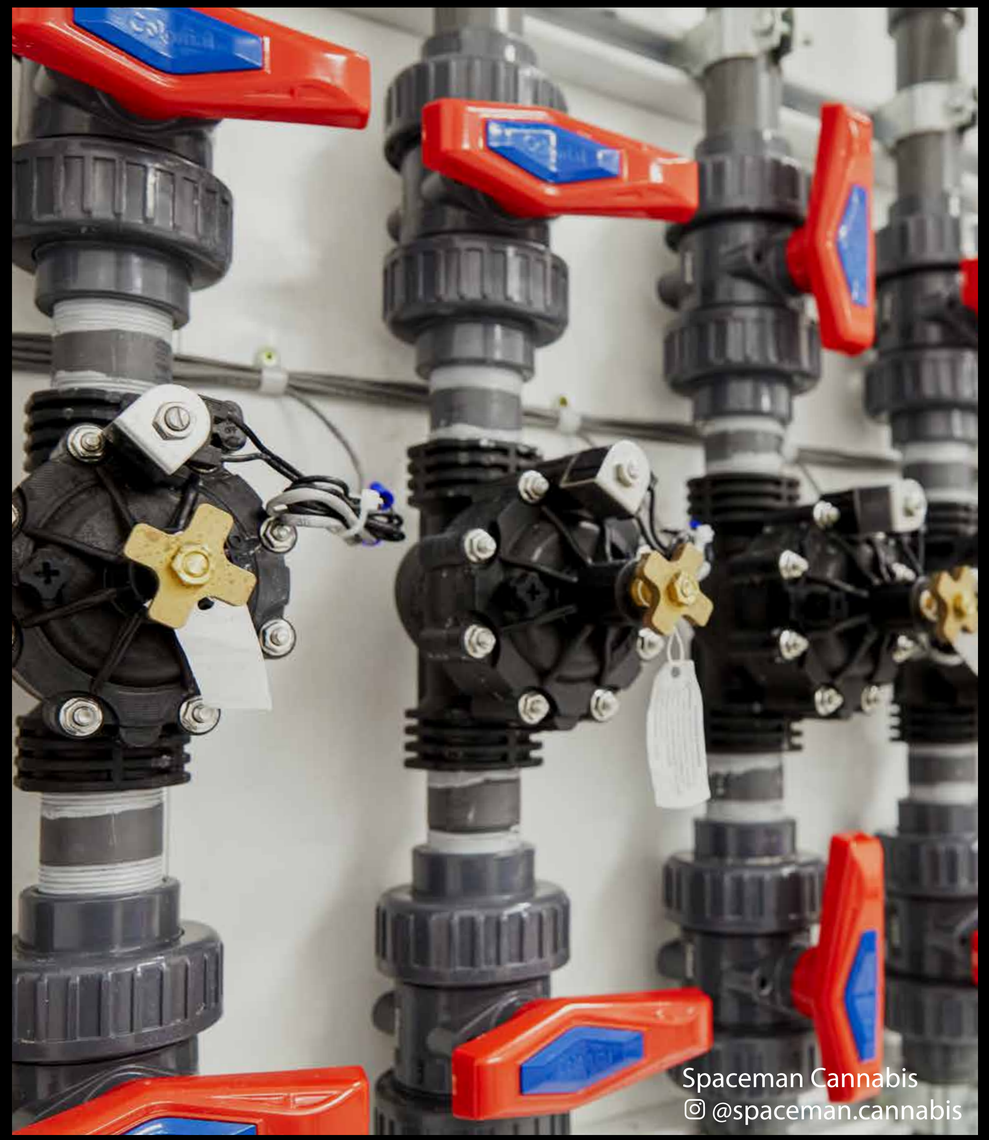
One of the most significant benefits of the TDR sensor is that propagation time is independent of the electrical conductivity of the substrate. Meaning, TDR sensors report the actual volumetric water content independent of soil electrical conductivity, compaction, and settling. TDR sensors don't require multiple equations for differing substrate types. Compared to a capacitance-based sensor, the TDR sensor is more complex and costs more to manufacture, but it is superior when measuring water content.

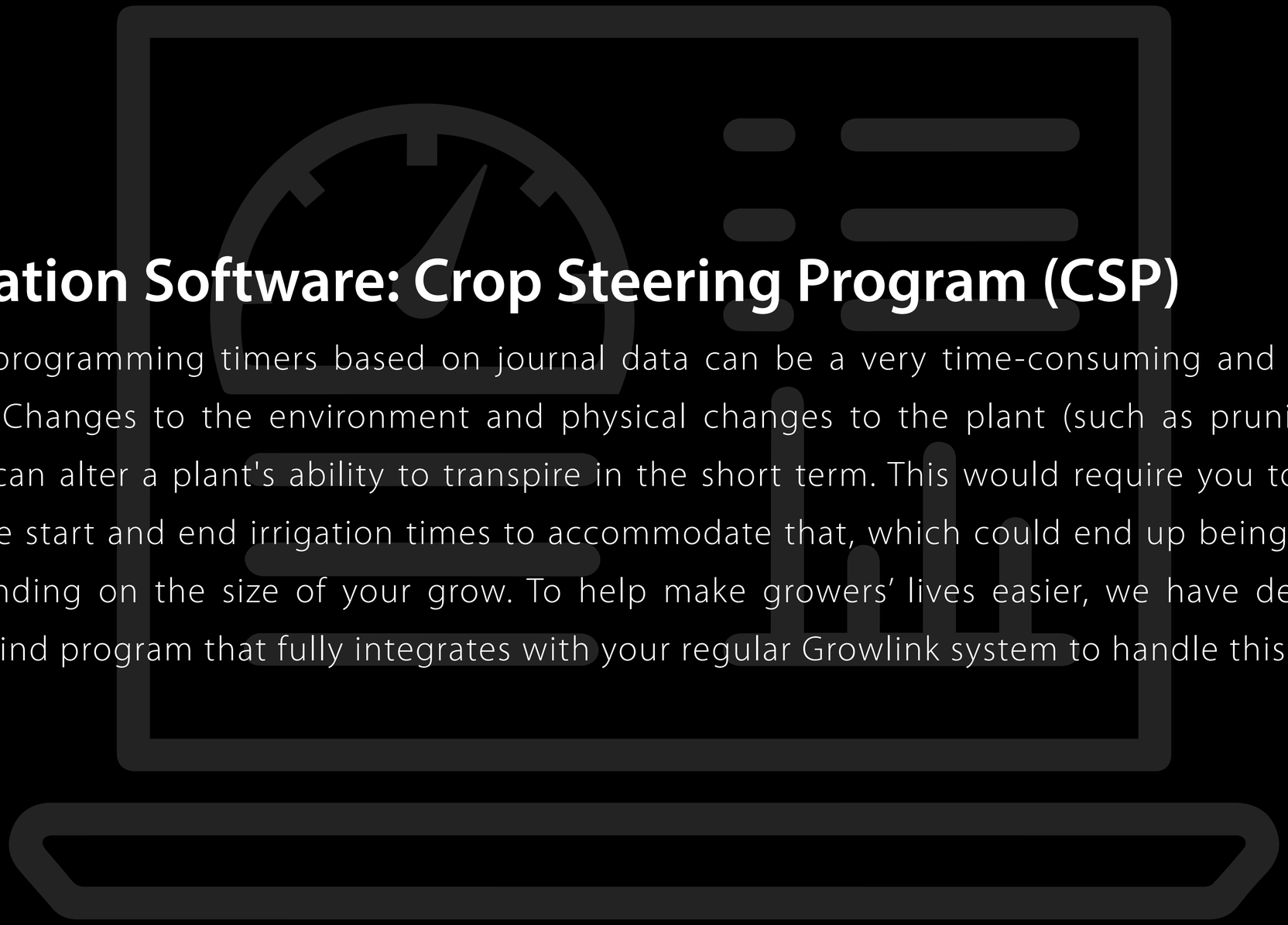
Precision Irrigation Controller

Connect up to 4 TDR Sensors and 4 Irrigation valves to the Growlink Smart Irrigation Controller. Use the Growlink App to visualize data, evaluate rules performance and test new optimizations. Deliver real-time data wherever and whenever you need it. Set the amount, frequency, and timing of irrigation events to steer growth. Our learning software enables you to save hours each day combing through data and adjusting irrigation timers, while ensuring the right decisions are made at the right time.

Valves

With the combination of batch tanks, and the ability to set custom Crop Steering Programs with unique setpoints per valve, it is often optimal to break up rows or tables into their own irrigation zones controlled by a unique solenoid valve. This is especially useful when growing multiple genetics in a single room as there is no one-size-fits-all solution regarding optimal setpoints, and growth needs often change from strain to strain.



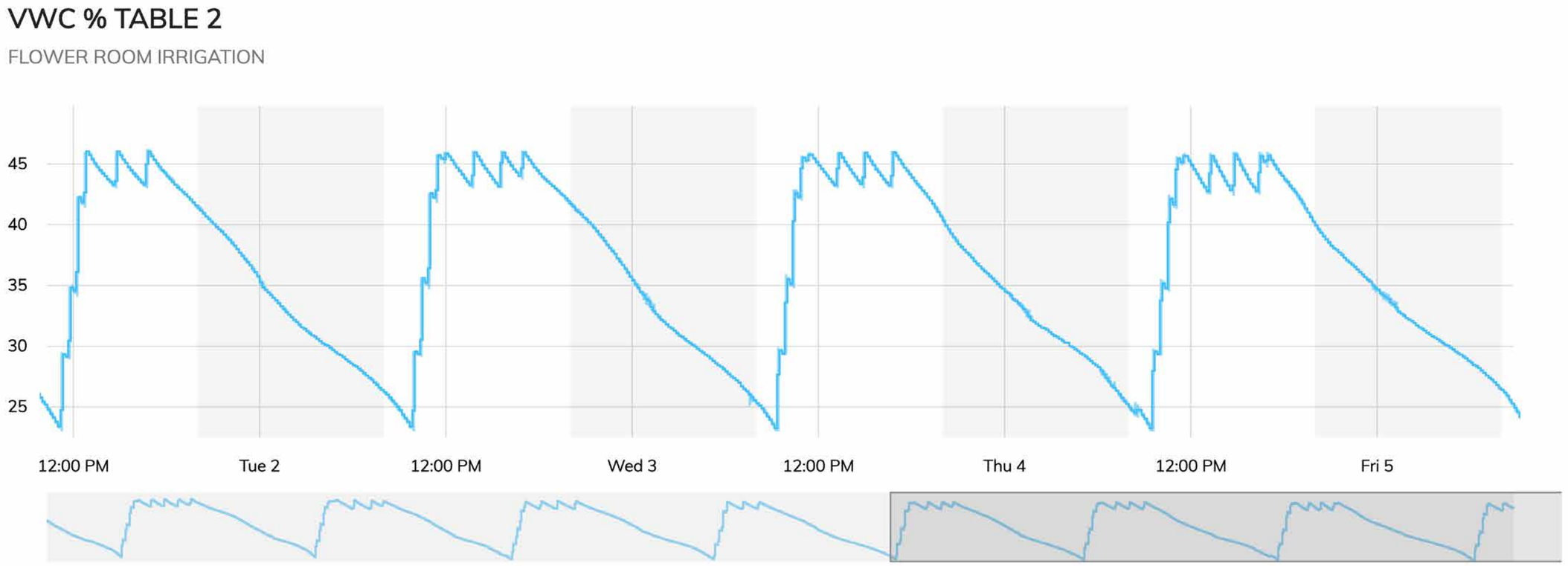


Cultivation Software: Crop Steering Program (CSP)

Manually programming timers based on journal data can be a very time-consuming and frustrating endeavor. Changes to the environment and physical changes to the plant (such as pruning or IPM spraying) can alter a plant's ability to transpire in the short term. This would require you to manually change the start and end irrigation times to accommodate that, which could end up being an all-day task depending on the size of your grow. To help make growers' lives easier, we have developed a one-of-a-kind program that fully integrates with your regular Growlink system to handle this for you.

Cultivation Software: Crop Steering Program (CSP)

Utilizing Growlink CSP, you will be able to enter your ideal setpoints for your specific genetics, and the program will automatically generate all irrigation events to achieve the desired parameters. This sophisticated AI program analyzes your substrate sensors' real-time data and doses your plants accordingly, freeing up your time to take care of everything else.

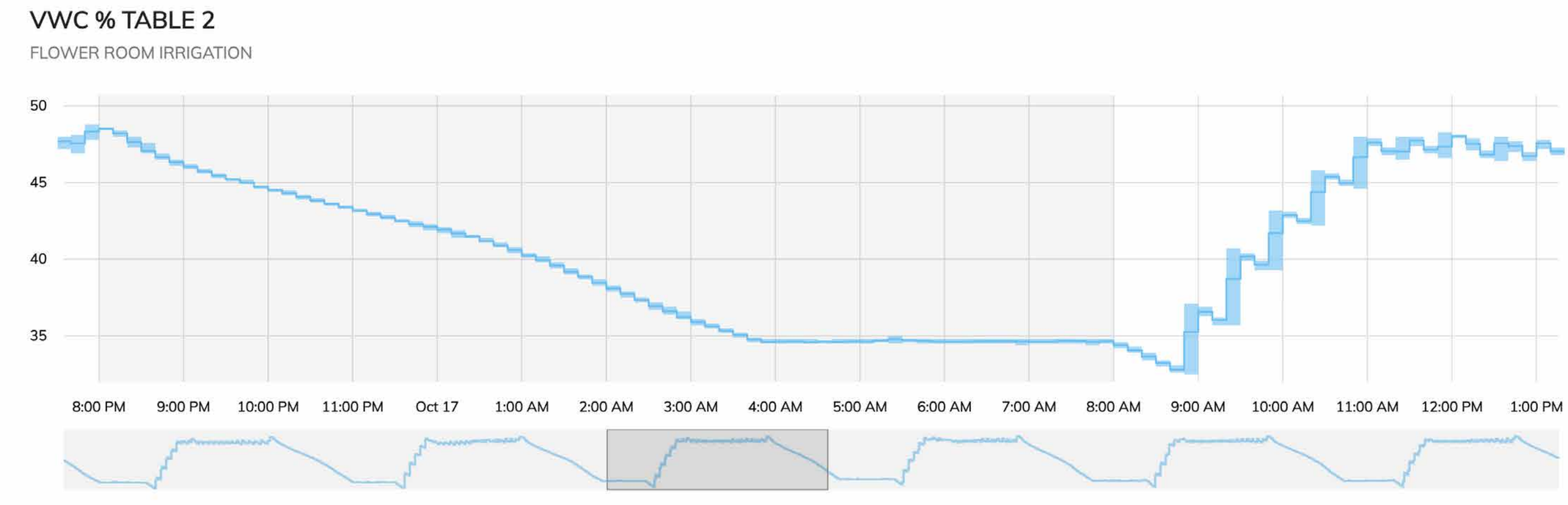


CSP
KEY FEATURES

Overnight Failsafe Protection:

It can be difficult to time your last irrigation event or your max target VWC% to achieve a perfect dry back. Oftentimes, you run the risk of drying back too quickly, causing your plants to wilt the following morning. This is no longer an issue as our Crop Steering program has included a built-in "overnight fail safe." The program will constantly monitor your substrate and give it an emergency shot if it falls below your target overnight VWC% and will continue to maintain it at that percentage until the lights come on the following day. While you don't want to make use of this regularly, it is a helpful tool to protect your crop and allow you to make the necessary changes to your setpoints for the following day. If you find yourself seeing multiple emergency shots happening throughout the night, you should either increase your max target VWC%, extend your last irrigation event to later in the day, or increase your total dryback percentage.

Overnight Failsafe Example:



Automatic P1 Delay

Temporary decreases in plant transpiration are inevitable. Whether you're facing cloudy days in a greenhouse, or you've recently sprayed or defoliated, temporary decreases in plant transpiration can occur, manifesting itself as a slower dry back than usual. While this is perfectly normal, it can become a nuisance depending on the size of your grow as you will need to adjust all of your irrigation timers to accommodate this decrease in VWC % loss to prevent over-saturation. From the time the lights turn on, the program will automatically begin counting down the additional dry back % that you specify, all while automatically delaying your P1 ramp up timers, until the set percentage has been satisfied.

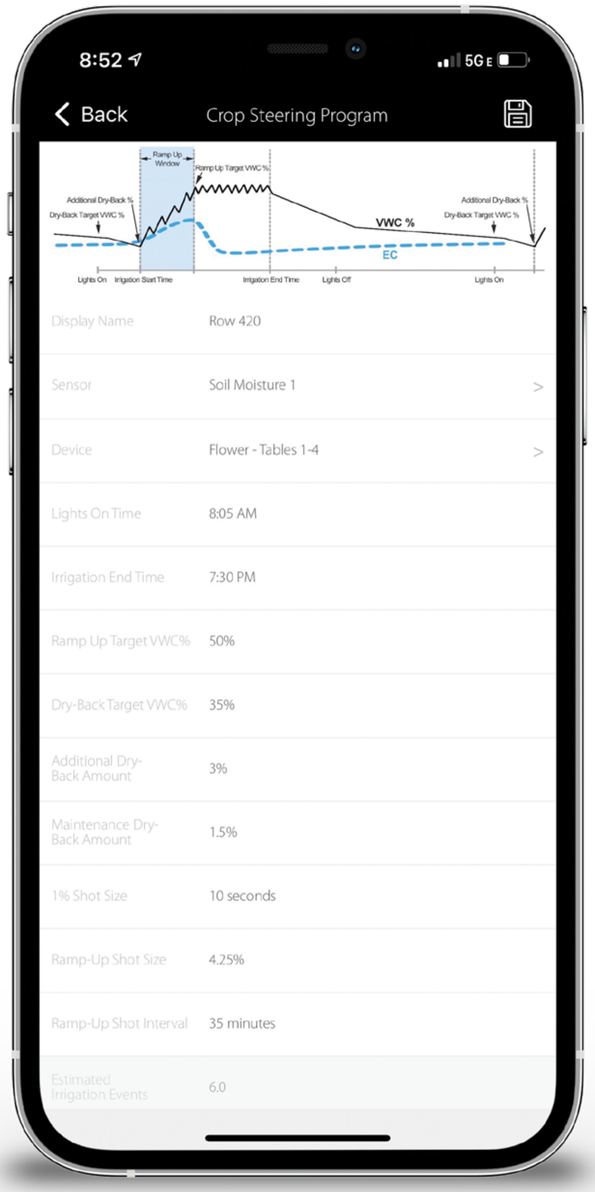
Maintenance EC Adjustment

Adjusting your substrates EC is crucial to crop steering successfully but can also be challenging to achieve without changing the EC of your feeds throughout the day. We kept this in mind when creating the Crop Steering Program, which is why you can specify your maintenance dry back %. Since the point of the maintenance phase is to maintain a set target VWC%, your shot size will always equal your dryback %. Being able to adjust this % gives you complete control over your substrate's EC. Increasing your target maintenance dryback % paired with lowering your target VWC % will increase the time between your shots, decreasing the chances for runoff to occur and allowing you to stack your substrate EC much more efficiently. Decreasing your target maintenance dryback % will decrease the time between your shots, causing more frequent smaller shots, which will increase your chances of runoff, essentially flushing your substrate EC out. Note, this process is not immediate and can take several days to reach desired levels.

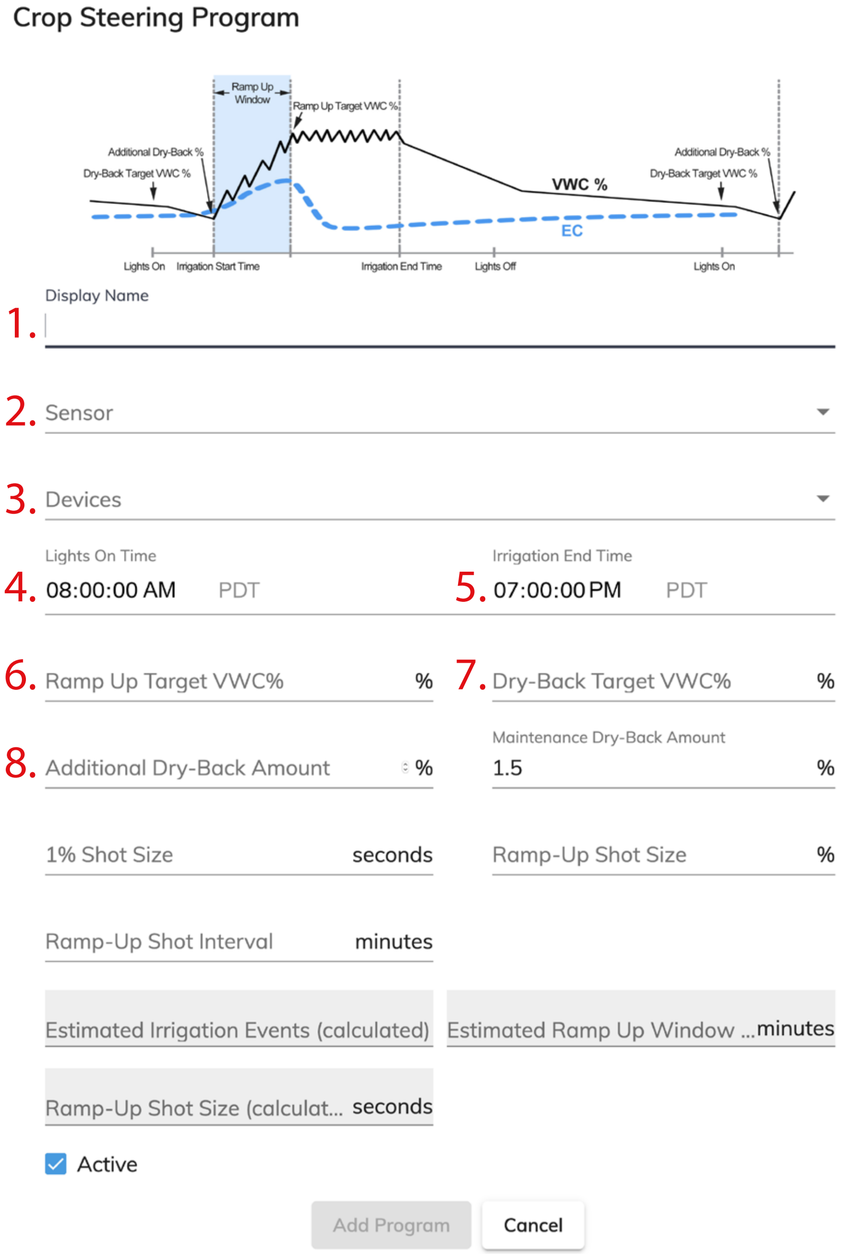
Using the Program

In your rules section, you will find a tab labeled Crop Steering. This is where you will create and manage all of your individual crop steering programs (CSPs).

Once selected, a dropdown menu will appear, allowing you to edit existing CSPs and create new ones. Clicking the 'Add Crop Steering Program' button will bring up the CSP form to enter your desired setpoints.



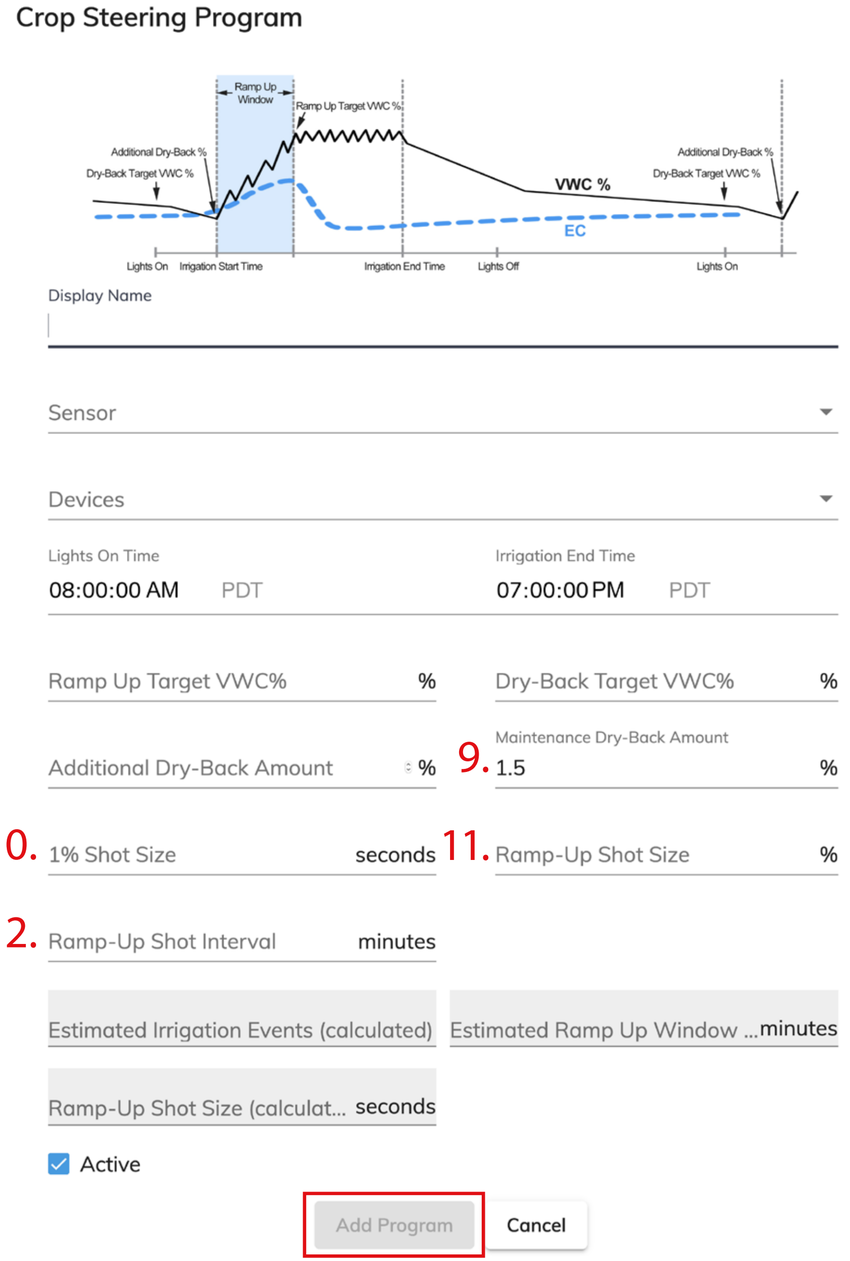
1. **Display Name**
2. **Sensor** - Select which probe or probe aggregate to source data from
3. **Devices** - Select which irrigation valves will be opened
4. **Lights On Time** - Defaults from your Profile Day Range
5. **Irrigation End Time** - Select the time of your last irrigation event of the day
6. **Ramp Up Target VWC%** - Enter the maximum VWC% you want to achieve for the day (Phase 1)
7. **Dry Back Target VWC%** - Enter the VWC% you want to achieve when the lights come on the following day (Phase3)
8. **Additional Dry Back Amount** - Enter the additional dry back % you wish to achieve after lights come on but before (Phase 1) begins (Phase 0)



9. **Maintenance Dry Back Amount** - Enter dry back %/shot size you want to achieve during the Maintenance Phase (Phase2)
10. **1% Shot Size** - Enter time it takes for your VWC% to increase by 1% (Instructions for calculation can be found in PIC Quick Start Guide)
11. **Ramp Up Shot Size** - Enter target shot size for Ramp Up (Phase 1)
12. **Ramp Up Shot Interval** - Enter frequency between Ramp Up shots (Phase 1)

At the bottom of the program, you will find your estimated calculations for your Phase 1 time period, including the number of irrigation events, estimated ramp-up time window, and your ramp-up shot size.

Once you have entered all of your specific target values, simply press '**Add Program,**' and the advanced AI will take care of the rest.



GLOSSARY

Actual Vapor Pressure (AVP): The measurement of water vapor in a volume of air.

CO2: A heavy odorless colorless gas formed during respiration and by decomposing organic substances; absorbed from the air by plants in photosynthesis.

Cola: The primary flower cluster that forms along the upper portion of the main stems and large branches in a mature female cannabis plant.

Crop Steering Program (CSP): Growlink cultivation software that automates irrigation events to follow crop steering strategy based on user inputs (setpoints) and sensor data.

Dry Back: The decrease of total VWC in the substrate from the last irrigation event.

Electrical Conductivity (EC): Water's ability to conduct an electric current. Salts or other chemicals that dissolve in water can break down into positively and negatively charged ions. These free ions in the water conduct electricity, so the water's electrical conductivity depends on the concentration of ions.

Humidity Deficit: The amount of water vapor that must be added to gas to achieve 100% humidity at a specific temperature.

Osmotic Pressure: The pressure produced by or associated with osmosis and dependent on molar concentration and absolute temperature such as the maximum pressure that develops in a solution separated from a solvent by a membrane permeable only to the solvent.

Photosynthates: (Botany) Any substance synthesized in photosynthesis, esp a sugar.

Photosynthetic Photon Flux Density (PPFD): The number of light photons that hit a surface in one second. Commonly measured in units called micromoles (µmols).

Pruning: The removal of branches or leaves from a plant.

Relative Humidity (RH): The amount of moisture in the air at a specific temperature compared to what the air can "hold" at that temperature.

Runoff: The water that drains from the substrate once the substrate has reached its field capacity.

Saturation Vapor Pressure (SVP): Vapor pressure or equilibrium vapor pressure is the pressure exerted by a vapor in thermodynamic equilibrium with condensed phases at a given temperature in a closed system. The equilibrium vapor pressure is an indication of a liquid's evaporation rate.

Shot: An irrigation event of a predetermined volume.

Substrate: The medium that a plant's root system grows in or on, such as Rockwool or coco coir.

Terpenes: Terpenes are organic hydrocarbons that produce the aroma and flavor in plants. Terpenes are formed inside cannabis trichomes, and their relative presence is directly affected by both the spectrum and intensity of light exposure.

Transpiration: The exhalation of watery vapor from the surface of the leaves of plants.

Trichomes: The resinous glands on cannabis buds that contain the plant's cannabinoids, terpenes, and other organic compounds.

Vapor Pressure Deficit (VPD): The difference between the Actual Vapor Pressure (AVP) and the Saturation Vapor Pressure (SVP). In plants, it is the difference in vapor pressure between the inside of the leaf and the vapor pressure outside of the leaf.

Volumetric Water Content (VWC): The ratio of the volume of water to the total substrate volume.

growlink™

800.432.0160 | info@growlink.com