RMJ SUPPLY™

HARNESSING METABOLISM

THE BIOLOGICAL FOUNDATION OF CANNABIS YIELD AND QUALITY

BALANCING YIELD AND QUALITY

Seasoned growers know that when crops are provided with the right environment and resources, the plants do most of the work to meet production needs. Since plants cannot move to find food or escape danger, they rely on complex biochemical processes, called metabolisms to survive. The commercial cannabis production goals can be summed up with two crucial and interconnected metrics: yield and quality. To maximize yields and quality, growers must know how these metabolisms are fueled and regulated so they can best be utilized. They are intertwined because yields of dried cannabis flowers are meaningless without also considering the quality of flower, commonly quantified as the concentration of active ingredients of cannabis.

From a biological perspective, yield and quality are products of plant metabolisms. Yield, typically measured as dried flower weight, is a product of primary metabolisms; photosynthesis and respiration, which generate biomass. Quality, usually quantified with cannabinoid and terpene concentrations, are products of secondary metabolisms, processes by which plants create a stunning diversity of chemical compounds. Understanding the mechanics and regulation of these metabolisms provide savvy cultivators with a competitive advantage, allowing them to better harness the biochemical machinery of their crops. Because primary metabolisms are mostly the same throughout the plant kingdom, much of what we already know about photosynthesis and respiration can be applied to cannabis cultivation. That said, quality or potency is more unique to cannabis, and is more complicated to address.

BECAUSE PRIMARY METABOLISMS ARE MOSTLY THE SAME THROUGHOUT THE PLANT KINGDOM, MUCH OF WHAT WE ALREADY KNOW ABOUT PHOTOSYNTHESIS AND RESPIRATION CAN BE APPLIED TO CANNABIS CULTIVATION

Production of secondary metabolites like cannabinoids and terpenes is controlled by complex and interconnected factors: environment, plant growth stage, and pruning techniques. To further complicate understanding the synthesis and regulation of cannabinoids and terpenes, the metabolism of each compound may compete with the metabolisms of other compounds for resources. We can speak more definitively about products of primary metabolisms (energy and biomass), and only in more general terms about secondary metabolites in cannabis. While there is still much to learn about the specifics of cannabis cultivation, many core principles of plant metabolisms can be applied. There is also a steady stream of exciting discoveries coming from the burgeoning field of horticultural cannabis research. This white paper will provide an overview of how primary and secondary metabolisms affect yield and quality, and how growers can take advantage of these natural processes through the use of lighting, environmental controls, and pruning techniques.

PRIMARY METABOLISMS: PLANT POWERHOUSES

The primary metabolisms, photosynthesis and respiration, are the processes by which plants capture, store and use solar energy. Plants can be viewed as solar-powered biochemical reactors. In the simplest terms, photosynthesis captures solar energy by reassembling water and carbon dioxide (CO_2) into sugars, whereas respiration consumes those sugars to generate energy. During photosynthesis, plants take in water, CO_2 and sunlight, and produce sugar and oxygen. Photosynthesis occurs in two steps: the light-dependent reactions, and light-independent reactions. The light-dependent reactions use light energy to split water molecules to generate energy which is then used in the light-independent reactions to reassemble chemically inert CO_2 into biologically available sugars. During respiration, sugars and oxygen are consumed to release energy (as well as water and CO_2 as byproducts) for growth and other processes like secondary metabolisms.

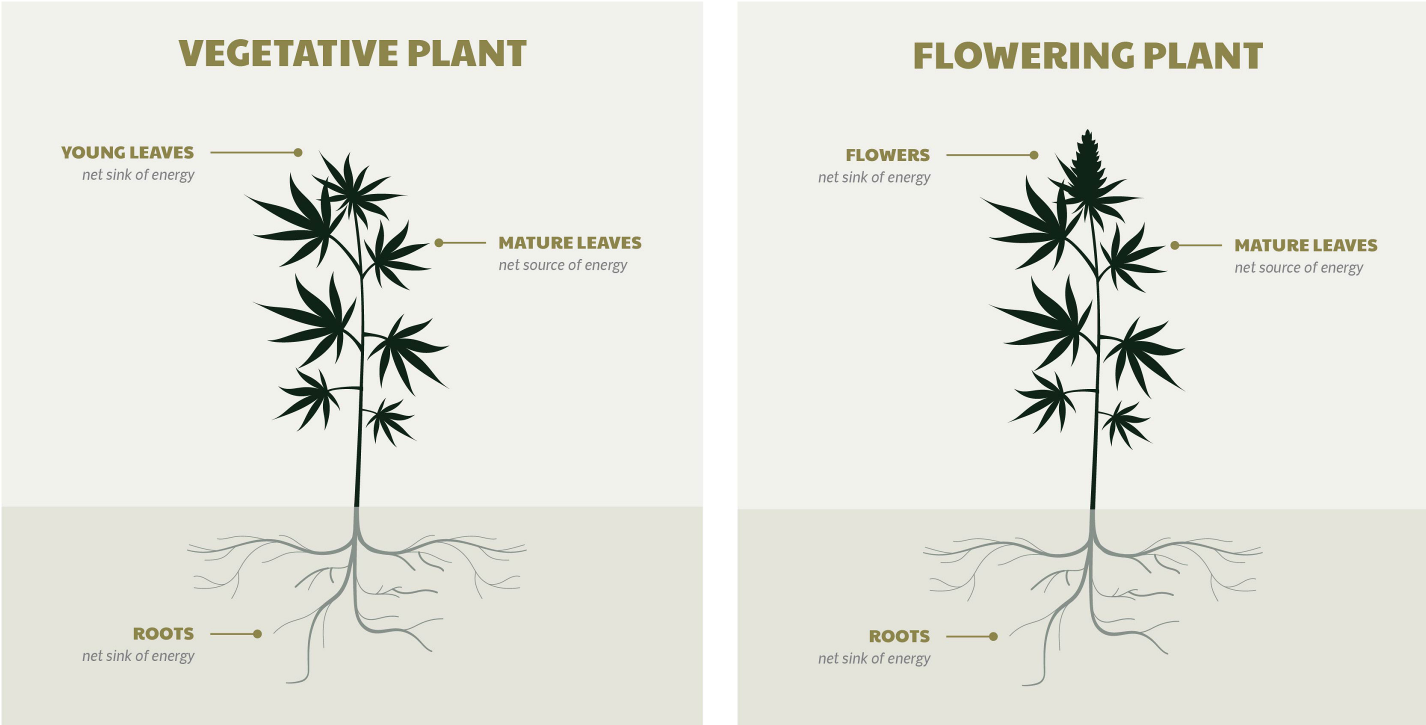

FIGURE 1 Energy sinks shift as plants change from vegetative to generative growth phases.

DIRECTING ENERGY FLOW THROUGH SINK-SOURCE RELATIONS

The rates of photosynthesis and respiration vary throughout parts of the plant, the day, and life cycle of the plant. Understanding these variations allows growers to take advantage of plants' natural metabolic machinery to meet production needs.
Plant parts can be grouped into producers (sources) and consumers (sinks) of energy. Mature leaves photosynthesize more than they respire, meaning they produce more energy than they require. Conversely, actively growing parts, roots, fruit and flowers all require more energy than they produce.
Leaves change their sink-source status over time. Young, actively growing leaves consume energy before they have reached full photosynthetic capacity, so they are sinks. Likewise, photosynthesis in older leaves becomes less efficient, especially when they become shaded out with younger leaves.
This understanding can be applied to pruning and defoliation practices in cannabis. Many growers believe that by removing plant parts, energy will be redirected to the remaining parts without considering whether they are removing a sink or a source. While aggressive defoliation during the flower stage may increase airflow and light penetration in the canopy, it will not redirect energy from leaves to flowers because leaves are sources; the flow of energy already goes from leaves to flowers.

PHOTOSYNTHESIS

CARBON DIOXIDE + WATER + LIGHT ENERGY =

GLUCOSE AND OXYGEN

Photosynthesis increases with more light intensity in the morning

RESPIRATION

GLUCOSE + OXYGEN =

ENERGY + CARBON DIOXIDE + WATER

Respiration takes over at night when there is no light to fuel photosynthesis

Respiration and photosynthesis rates are directly influenced by environmental cues typically related to daily cycles. Unsurprisingly, photosynthesis increases with more light intensity in the morning and respiration takes over at night when there is no light to fuel photosynthesis. Both primary metabolisms are also temperature dependent, peaking at a particular temperature. Photosynthesis depends on a steady supply of CO_2 which enters the plant through tiny pores on leaves called stomata. Stomata are also one of the main routes for water to leave plants, so stomata will generally close when plants are experiencing water stress (dry root zone, low air humidity, excessive heat or light) and open when water is not of concern (moist root zone, high humidity etc.).

Over the lifecycle of a plant, different sinks differ in strength, pulling different proportions of energy from sources. Cannabis is a short-day annual plant, meaning that shorter day lengths (usually ≤12h) prompt it to flower, completing its lifecycle and dying before winter. Thus, anything a grower can do to mimic the approach of winter will drive floral development. During longer days, cannabis plants are in the vegetative growth stage in which they build structure and size making young shoots and leaves the strongest sinks. As days grow shorter and nights turn cooler, the flowering stage progresses, and flowers become stronger sinks.
Flowers can become such a strong sink that they can turn older leaves that would otherwise be sinks back into sources. As flowering progresses, discoloration in older leaves may be a sign that the plant is remobilizing the nutrients and energy to fuel flower growth and development.

With consideration of sink-source relations in mind, growers should try to maximize photosynthesis (source efficiency) during the vegetative and early flower stages to build biomass and energy for flower development. Likewise, growers should aim to encourage respiration, sink strength of flowers, and secondary metabolisms later in the flowering stage. To maximize photosynthesis, mature leaves (source) should be kept on the plant early on and removed as they become older or completely shaded. A mild environment with ample water and CO_2 also facilitates photosynthesis in the early growth stages. As flowering progresses, older leaves should continue to be removed, both to increase air and light penetration into the canopy, and to remove sinks. For reasons more related to secondary metabolisms than to sink-source relations, a drier root zone and atmosphere is more conducive to flower development. To drive vegetative or floral growth at the appropriate times, it is critical to have good environmental and irrigation controls.

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WHILE BEST PRACTICES HAVE NOT YET BEEN ESTABLISHED FOR CANNABIS CULTIVATION, RECENT STUDIES HAVE SEEN GAINS IN PHOTOSYNTHETIC RATE UP TO 1500 µMOL/M2/S

USING LIGHT TO INCREASE YIELDS

Cannabis is a high light intensity crop but how do we know when we are providing the correct amount of light? For photosynthesis, plants use light wavelengths in the red and blue spectra, also called photosynthetically active radiation (PAR). Other light measures such as Lux or Lumens are measures of

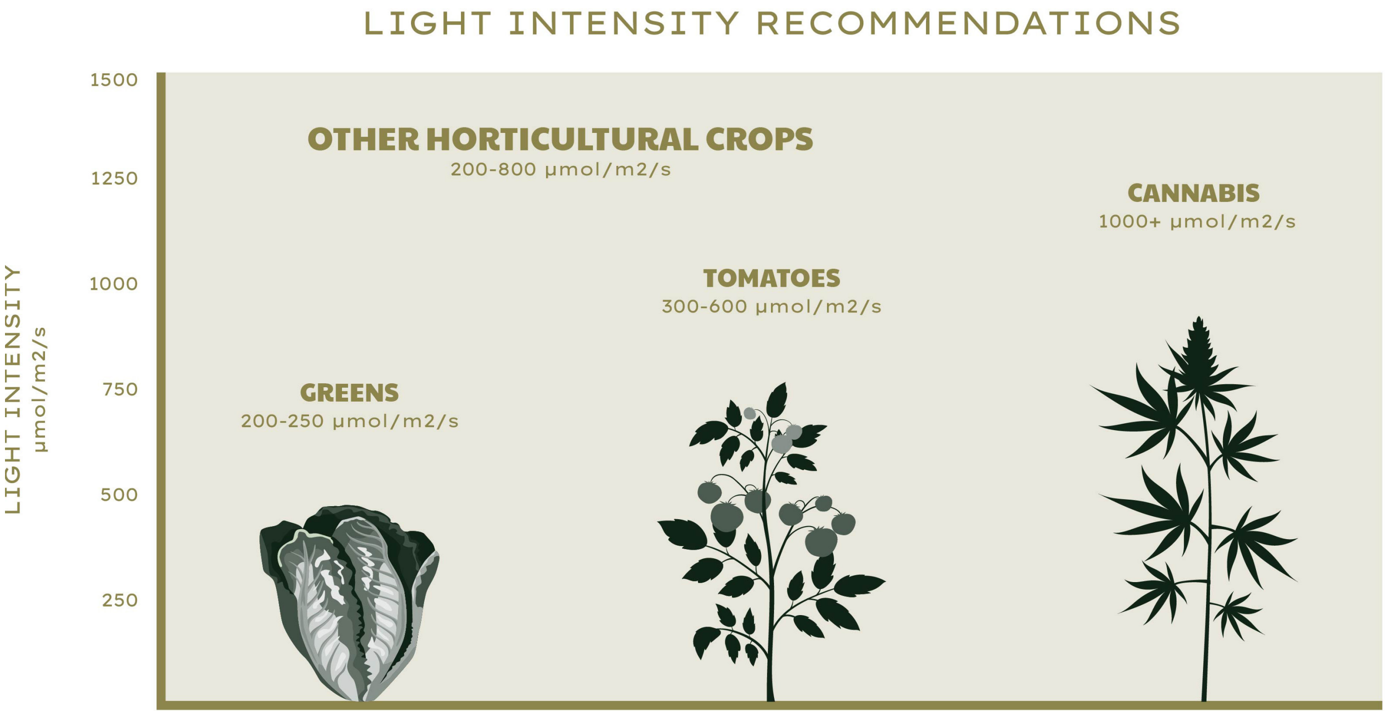

FIGURE 2 Cannabis has higher light requirements than other common horticultural crops.

visible light, so are not directly applicable to horticultural lighting. PAR is expressed as Photosynthetic Photon Flux Density (PPFD) with units of micromole-per-meter squared-per-second (µmol/m2/s). While PAR is the force driving photosynthesis, and thus yields, there is a growing body of evidence that proportions of PAR wavelengths and even wavelengths outside the PAR range, such as infrared and ultraviolet, have important effects on growth and development of cannabis, particularly on the regulation of secondary metabolisms. A higher ratio of red to blue wavelengths appears to increase yields [1].

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ANY FACTOR AFFECTING PLANT GROWTH CAN ONLY CONTRIBUTE TO GROWTH OR YIELD AS MUCH AS THE MOST LIMITING FACTOR

Each plant species has a "light saturation" point at which photosynthetic rate is maximized, and beyond which photosynthetic rate plateaus or even declines. Maximum light intensity recommendations for most horticultural crops during fruiting or flowering are in the 600-800 µmol/m2/s range while most recommendations for cannabis are closer to 1000 µmol/m2/s.

Any factor affecting plant growth can only contribute to growth or yield as much as the most limiting factor. For example, if a crop is receiving the optimum lighting intensity but not enough water, water will become the limiting factor and the potential gains from light intensity will be negated. Using this principle, we see that light saturation points are relative to water, temperature, nutrients and all other growth factors. While best practices have not yet been established for cannabis cultivation, recent studies have seen gains in photosynthetic rate up to 1500 µmol/m2/s [2]. A recent study showed increases in yields and flower density up to 1800 µmol/

m2/s while photosynthetic rate leveled off at a lower light intensity [3]. While the research is relatively new, it is clear that high light intensity equated to higher yields.

Considering the significant light requirements, it becomes clear why providing cannabis crops with ample, high-quality light is important for maintaining optimal production. Two unique cannabis cultivation attributes come into play when choosing lighting. First, to produce a consistent, safe, medical-grade product, cannabis is frequently grown indoors under entirely artificial light, and second, cannabis has a very high light requirement. With these two considerations in mind, growers must wrestle with the fact that while more light produces a higher yield, more light also comes at a higher cost. The use of quality lights to maximize both yields and efficiency is critical.

Two of the most popular types of lights used in commercial cannabis cultivation are high-pressure sodium (HPS) lamps and light-emitting diodes (LEDs). HPS have been the preferred lighting source for decades because they are fairly efficient at converting electrical energy into PAR. They have been particularly well-suited for the flowering stage because they provide more of a red spectrum which promotes reproductive growth. HPS also generates a lot of heat which requires more cooling capacity and can be expensive to maintain.

GOOD ENVIRONMENTAL CONTROLS AND HIGH-QUALITY LIGHTING ARE ESSENTIAL TO HARNESSING THESE SECONDARY METABOLISMS

LED technology has progressed quickly over the last 20 years. Currently, LED fixtures provide a variety of spectral profiles and are much more efficient than HPS. They also generate less heat than HPS requiring less cooling capacity. The main drawback of LEDs is the significant financial investment that they require.

Two strategies can be employed when replacing HPS with LED fixtures: matching light intensity and matching wattage. LEDs can provide light intensity equal to HPS with less wattage, so matching the light intensity of an HPS layout will lower energy use, while matching HPS wattage will increase overall light intensity.

IN A RECENT STUDY, PLANTS GROWN UNDER HIGH QUALITY LEDS PRODUCED HIGHER YIELD AND POTENCY THAN THOSE GROWN UNDER HPS

While LED layouts require less cooling capacity, higher light intensities produce larger, more vigorous plants that produce more humidity and require more dehumidification capacity. In a recent study, plants grown under high quality LEDs produced higher yield and potency than those grown under HPS [5]. Lighting choice should aim to maximize both light intensity and efficiency.

BOOSTING SECONDARY METABOLISMS TO IMPROVE FLOWER QUALITY

While yield is an essential metric for producers, the overall biomass cannot be

decoupled from flower quality.
Most flower quality attributes such as density, smoke quality, and appearance are difficult to quantify, so quality is often measured as potency, or the concentration of cannabinoids and terpenes. Many have even proposed classifying cannabis by their chemical profile or “chemotype” rather than traditional “Indica” and “Sativa” classifications. While cannabis produces hundreds of cannabinoids and terpenes, tetrahydrocannabinol (THC) remains the most valuable and marketable secondary metabolite. THC is the most abundant and most psychoactive cannabinoid but there is a growing understanding of the synergistic effects of cannabinoids and terpenes called “the entourage effect”. As the cannabis market matures, quality measures such as Total Active Cannabinoids (TAC) and terpene profiles are starting to be used to differentiate higher quality flower from those with only a high THC concentration.

To increase the production of secondary metabolites, one must consider the role they play in the plant. While the evolutionary purpose of cannabinoids is still somewhat of a mystery, there are several hypotheses, all suggesting cannabinoids as defense chemicals. We also know that cannabinoid production is regulated by a complex interplay of primary and secondary metabolisms and plant hormones. Plants cannot run from danger, so they produce physical and chemical defenses from environmental stresses, diseases, and herbivores. Both cannabinoids, terpenes and trichomes, the hair-like structures that house them, may act as defenses.

Cannabinoids are concentrated in trichomes that protrude from female cannabis flowers and leaves. These trichomes act as a physical defense against inhospitable environments and herbivores. By covering the surface of flowers and leaves, trichomes trap both moisture and air close to the plant, insulating it from the surrounding environment and buffering them against dry air or extreme temperatures. Trichomes may also protect plants from intense light by absorbing or refracting light before reaching more vulnerable cells in the flower and leaves.
There is speculation that giving plants environmental cues stimulates them to channel more resources to trichome development and cannabinoid production. This is an early-stage theory, but there is a growing body of evidence supporting it.

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RECENT STUDIES HAVE SHOWN ENVIRONMENTAL CUES SUCH AS CONTROLLED DROUGHT STRESS, SALT STRESS, AND UV EXPOSURE INCREASE YIELD AND CANNABINOID CONCENTRATION

Recent studies have shown environmental cues such as controlled drought stress [3], salt stress [6], and UV exposure [7] increase yield and cannabinoid concentration.
Light appears to have a direct influence on cannabinoid production with pruning techniques to increase light penetration [8] and subcanopy lighting [9] both increasing cannabinoid production and consistency throughout the plant. The ratio of red to blue wave lengths also influence the relative production of cannabinoids with red producing more THC [10] and blue producing more CBG [11].

Secondary metabolites in plants, particularly terpenes often act as a chemical defense against herbivores and pathogens. Some will repel insect pests with odors, some will make plants unpalatable to mammalian herbivores, and others, like THC, are natural antimicrobials. Wounds produced during pruning may simulate herbivory and a variety of pruning techniques have been shown to increase cannabinoid concentrations and consistency [8]. Beneficial microbes may stimulate plants pathogen response and increase secondary metabolite production as well [12]. Burgeoning research into cannabis horticulture shows that deeper understanding of the complex regulation of secondary metabolites will provide many novel approaches to increase production of valuable secondary metabolites in the coming years. As with primary metabolisms, good environmental controls and high-quality lighting are essential to harnessing these secondary metabolisms.

CONCLUSION

Plants have the remarkable ability to produce an incredible variety of useful compounds using the basic ingredients of light, water and CO_2. It is up to the savvy grower to provide plants with the proper environment and resources at the appropriate times to direct plant metabolisms toward their production goals. Some would argue that plants have domesticated humans to meet their needs just as much as we have domesticated them to meet ours. In the controlled indoor environment that characterizes much of the cannabis industry, it is crucial to have environmental controls in place to satisfy the plants' needs and direct metabolic flows. Light is one of the main factors limiting yields. Increased lighting increases yields up to a point but levels off at a certain intensity. The upper limit of lighting for cannabis is still unknown. This is a good argument for getting high quality lights.

KEY TAKEAWAYS

Plant growth (fueled by photosynthesis and respiration) is limited by the most limiting growth factor (e.g. temperature, humidity, water, nutrients). At a commercial scale, automation equipment is essential for balancing all growth factors.

The light saturation point for cannabis has not yet been established so we can assume that more light is better. If all other growth factors are balanced, lights that deliver the highest PAR light intensity increase yields.

Good environmental systems with quality HVAC components and automation allow growers to drive the correct metabolisms at the correct growth stages and apply controlled stresses to increase cannabinoid and terpene production.

Pruning and defoliation can increase yields and potency but it is important to keep sources when photosynthesis is needed and remove non-floral sinks when respiration in flowers is needed.

Research into the effects of spectra on plant growth, development and secondary metabolite production is gaining momentum so spectral control will allow growers to quickly take advantage of the latest development in cannabis photobiology.

ABOUT THE AUTHOR

Jack Lamont is a horticulturist, plant scientist, and commercial cannabis grower. He is on a mission to stamp out myths and misconceptions in cannabis cultivation using established plant science and emerging cannabis research. With more than a decade of experience in horticulture, he has led cultivation departments of cannabis production facilities in Canada and The United States. He has also authored numerous scientific and trade journal articles, served on various scientific committees, and recently founded a biodynamic vegetable, herb, and poultry farm with his family in Keene, New Hampshire.

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