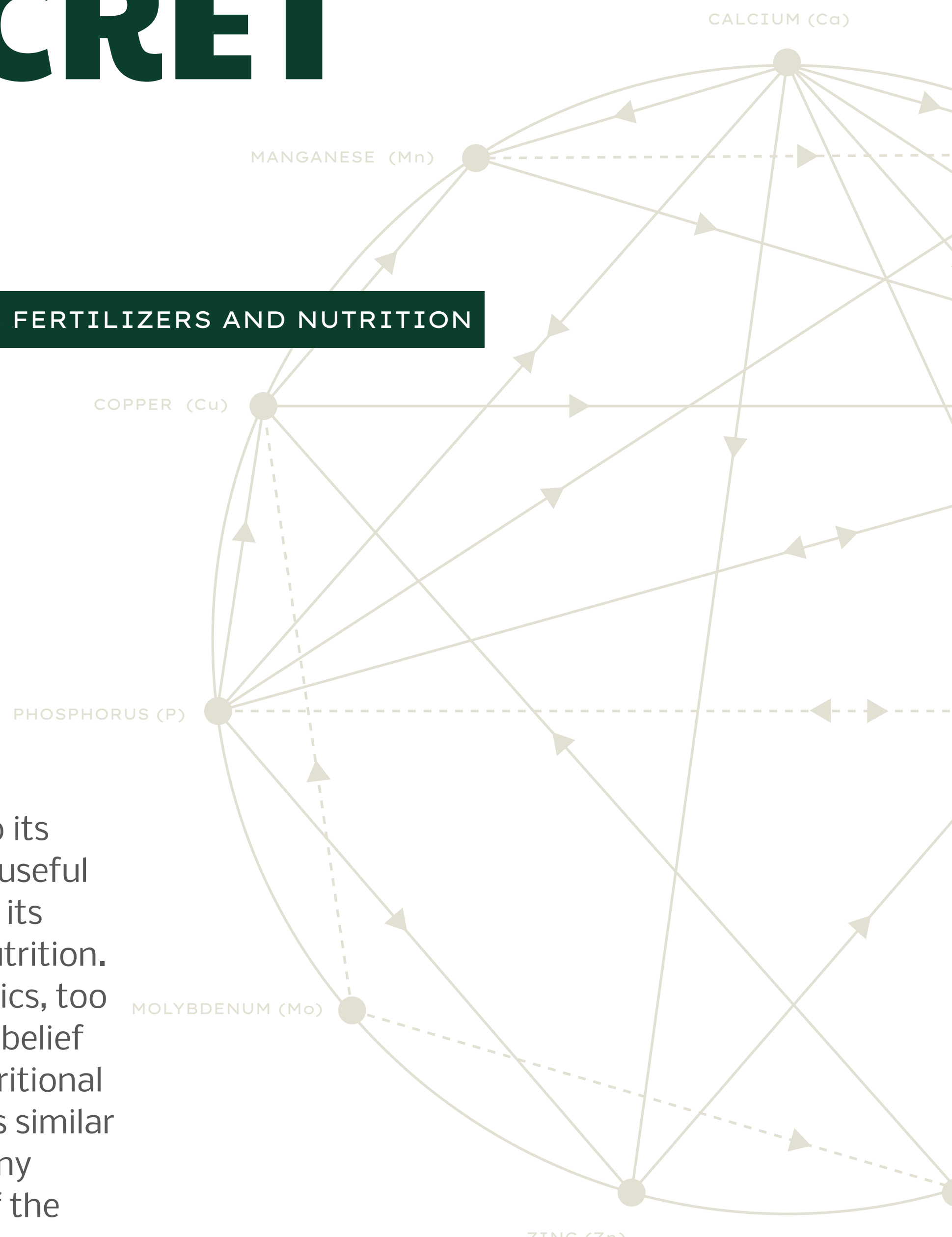
DEMYSTIFYING THE SECRET SAUCE

THE CHEMISTRY BEHIND CANNABIS FERTILIZERS AND NUTRITION



As a crop, cannabis stands out due to its ability to produce a dizzying array of useful compounds, its fast growth rate, and its large appetite for light, water, and nutrition. Despite these distinctive characteristics, too much weight has been placed on the belief that cannabis has very particular nutritional requirements, when, ultimately, it has similar nutritional needs to other plants. Many fertilizer companies have profited off the perception that cannabis needs a dozen different bottles of secret sauces to flourish. In reality, cannabis requires the same 17 nutrient elements that all plants require. The information here will allow growers to sift through claims made by fertilizer companies to find the best quality and value for their specific needs.

Nutrients are essential for all biological processes in plants. Although they are all vital for growth and development, each nutrient is required in different quantities at different stages of growth. Nutrients are generally split into four categories: macronutrients, secondary nutrients, micronutrients, and the elements taken from the air and water. Macronutrients are required in the greatest quantity and are the nutrients that most commonly limit growth. Secondary nutrients are needed in lesser quantities but still commonly limit growth. Micronutrients are needed in extremely small quantities and are often toxic at higher concentrations. Carbon, hydrogen, and oxygen are taken from water and the air and typically are not considered when discussing plant nutrition.

NUTRIENT AVAILABILITY AND DEFICIENCY

Nutrients limit growth if they are not available to plants in sufficient quantities. Plant growth is limited by the most limiting nutrient. For example, if all other nutrients are provided at the optimal rate, but phosphorus is applied at half the optimal rate, plant growth will be limited to whatever can be supported by half the optimal phosphate (Figure 1). Nutrient deficiencies directly impact growth and yield before there are any visible symptoms (Figure 2), so it is important to have a well-designed fertilizer regime that is closely monitored through testing irrigation water, runoff, and leaf tissue nutrient content.

Each nutrient is mobile to different degrees, both in the root zone and in the plant. Field soils are generally much more reactive, meaning nutrients stick to them more, than soilless media, such as peat, coir and rockwool which are characteristic of commercial cannabis cultivation, thus issues of nutrient mobility in field soils are usually

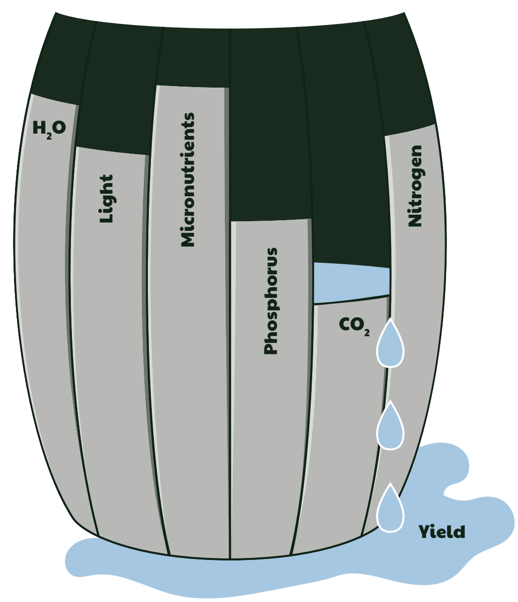


FIGURE 1 Justus von Liebig, the 19th century agricultural chemist who is often credited as "the father of the fertilizer industry", was the first to recognize that plant growth is limited by the most limiting nutrient. Liebig's "Law of The Minimum" is often depicted as a barrel holding the potential yield of a crop and the shortest staff representing the most limiting nutrient.

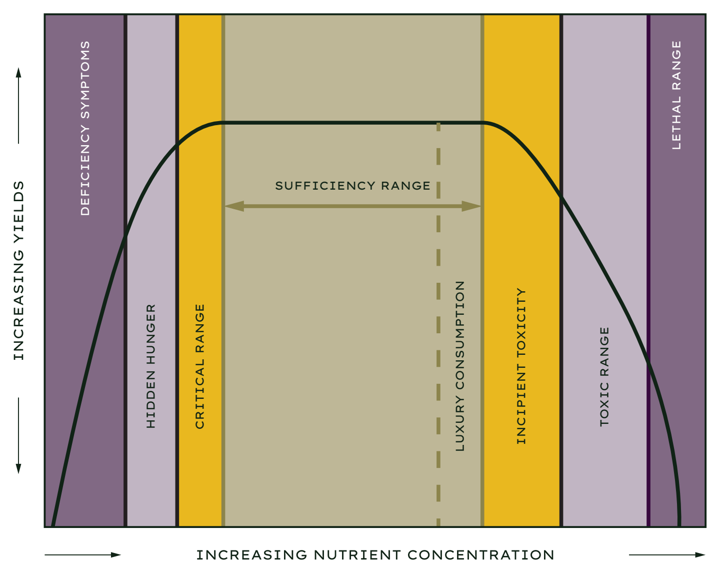


FIGURE 2 Plants respond to fertilizers along a predictable curve. Plants show visible symptoms of deficiency and significant losses of growth and yield in the "deficiency" range. While deficiency symptoms are on visible, there are yield losses in the "hidden hunger" range. The "critical" range is where crops get close to potential yields. Plants reach there potential yield in the wide "sufficiency" range. Higher rates in the sufficiency range result in "luxury consumption" which is a waste of nutrients. Rates higher than the sufficiency range are toxic.

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PLANT GROWTH IS LIMITED BY THE MOST LIMITING NUTRIENT.

not as common in soilless media. Nutrients can still become immobilized or converted to forms that are unavailable to plants in soilless media; this is a phenomenon often called "lockout". Lockout occurs due to imbalances in the ratios of particular nutrients or pH outside the optimal range. Many nutrients are antagonistic to the uptake of other nutrients, meaning if some nutrients are too abundant, they make it more difficult for plants to take up other nutrients (Figure 3).

Once inside plants, some "mobile" nutrients can be relocated to where they are needed. Other "immobile" nutrients have more difficulty moving from where they initially land. Because of differences in mobility, symptoms of deficiencies in nutrients can be seen in different parts of the plant. Symptoms of mobile nutrient deficiencies show up in older leaves, whose nutrients have been remobilized for active growth points, whereas those of immobile nutrients show up in newer growth.
Nutrient uptake is not only determined by the quantity of nutrients applied, but by interactions with the plant and environment, and between nutrients. Plants require different quantities and ratios of nutrients at different stages of growth and the growth cycle of cannabis is so fast and dynamic that feeds should change every couple of weeks to meet the plants changing needs. For example, cannabis requires more nitrate during the vegetative stage and less later in flower.
Nutrient availability is greatly affected by the pH of the growing media, with some nutrients becoming less available under acidic conditions and others becoming unavailable

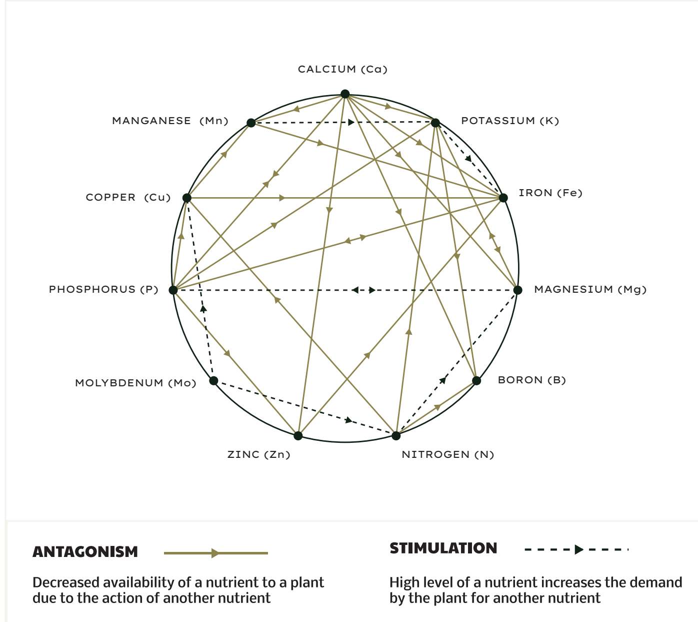

FIGURE 3 Mulder's Chart shows antagonistic (nutrients that interfere with one another's uptake) and synergistic (nutrients that aid in one another's uptake) relationships between essential plant nutrients.

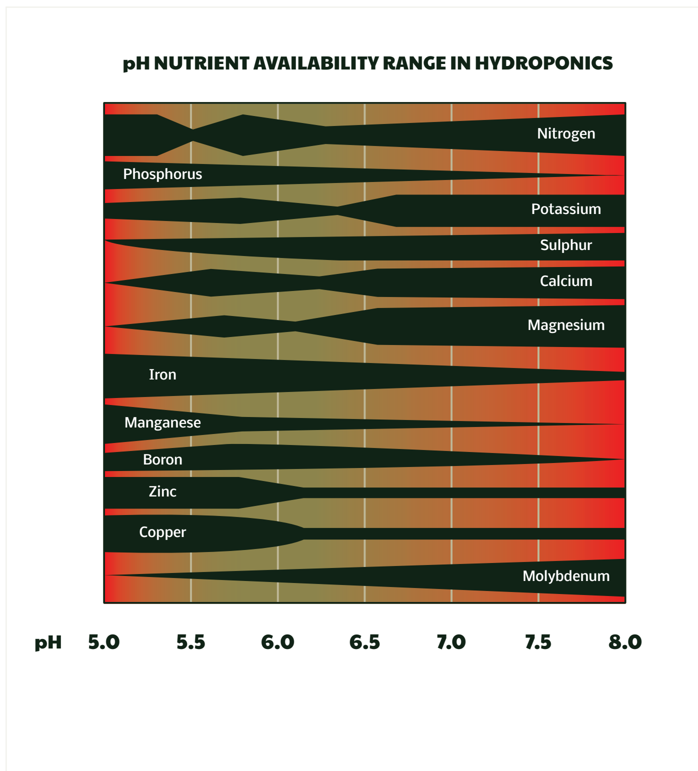

FIGURE 4 Nutrients become more available or less available across pH ranges. In growing media, most nutrients are available in the range of 5.8-6.2.

in alkaline media. In growing media, nutrients are most available in a pH range of 5.8-6.2 (Figure 4). Many micronutrients are applied in a "chelated" form where they are fused with an organic molecule to make them available across a wider pH range.

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Some nutrients, particularly calcium, rely on movement of water through the plant for transportation, so environmental factors that slow the movement of water like high humidity or cold temperatures can reduce nutrient availability. Other nutrients, like nitrogen, require warm temperatures to be converted to plant available forms.

MACRONUTRIENTS: N-P-K

Plants need nitrogen (N), phosphorus (P) and potassium (K) in larger quantities than other nutrients and they are the most commonly deficient nutrients. In cannabis, the need for these nutrients changes throughout the growth cycle with N needed more in the vegetative and early flower stage, and P and K needed more as flowering progresses.

Fertilizer labels are required to display a "guaranteed analysis" listing the guaranteed minimum percentage of N, P (in the form of phosphate) and K (in the form of potash) contained in the fertilizer. The guaranteed analysis is shown as three numbers on the front of the bag (e.g. 20-30-10)

Nitrogen is available as nitrate, ammonium, or urea. A larger proportion of nitrate is best for cannabis grown in a controlled environment because it has the least effect on root zone pH. Urea converts to ammonium and ammonium converts to nitrate. At each of these steps, the pH is lowered. Furthermore, when plants absorb ammonium directly, the pH is lowered once more. Nitrate may slowly raise pH over time but can be balanced with a small proportion of ammonium. Many fertilizers marketed toward cannabis contain an excessive amount of P, often many times more than any other crops use, and more than any plant could absorb. The excess P can build up the root zone and harm plants through salt damage or reducing availability of other nutrients like K, calcium (Ca) and iron (Fe) [1].

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SECONDARY NUTRIENTS AND MICRONUTRIENTS

The secondary nutrients, calcium, magnesium (Mg), and sulfur (S) are still required in significant quantities and are frequently deficient. In fertilizers marketed to cannabis, calcium and magnesium are often strangely grouped together as "Cal-Mag." Because of this, the application of fertilizer and diagnosis of deficiencies are wrongfully combined. Ca and Mg are, in fact, distinct elements which are taken up differently, required in different quantities, perform different roles in plant biology, and display different deficiency symptoms (Table 1). Because Ca movement is so reliant on the movement of water through plants, deficiencies are commonly related to environmental factors that slow transpiration. Because Ca is so immobile, foliar applications can be a good choice in transpiration-limited circumstances. Conversely, magnesium is a somewhat mobile nutrient.

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S is often overlooked in nutrient programs but can be required in similar amounts as macronutrients. The symptoms of sulfur deficiencies are like those of N deficiencies due to the important role of sulfur in N metabolism.

Micronutrients are elements that are required by plants in very small quantities, and in most cases, become toxic to plants at higher concentrations. Micronutrients are needed for various essential processes such as photosynthesis, reproduction, N uptake and energy transport. The roles of some micronutrients are still not fully understood. It is often difficult to diagnose micronutrient deficiencies because many micronutrient deficiency symptoms are so similar. Micronutrient deficiencies are often related to pH as the availability of most micronutrients declines sharply outside a specific pH range. Many micronutrients are best supplied as chelates to ensure availability across a wider pH range.

FORMULATIONS

Plants absorb nutrients as charged molecules called ions. Generally, plants always absorb nutrients as the same ion, for example, calcium is always absorbed as the same Ca2+ ion, regardless of the source material. A Ca2+ ion from calcium nitrate is the same Ca2+ ion from the hottest bottled “nute line” which is the same Ca2+ ion from organic bone meal. All plants, including cannabis, take up the same nutrients. The main differences in fertilizer formulation are:

- The ratios of nutrients to one another
- How it is applied
- How it affects the chemistry and biology of the root zone
- How readily nutrients are available across different conditions (ph, t etc)

Chemical fertilizers are blended from highly soluble salts with known chemical compositions. When compared with organic sources, chemical fertilizers are more predictable because they supply nutrients in ionic forms that are readily available to plants. Additionally, they are often less expensive than organics and less likely to clog irrigation equipment.

Premixed chemical fertilizer blends are often marketed to the cannabis industry as “nutrient lines” with various component fertilizers added at different ratios throughout the grow cycle (e.g. grow, bloom, etc.). The main differences between nutrient lines are how they are stored (liquid or dry), what chemical salts are used, and at what ratio nutrients are delivered. Other differences could include packaging, dyes, anti-clumping agents and other additives.

Nutrient lines can be quite expensive, with some feed schedules calling for over a dozen different products throughout a grow cycle. Liquid formulations are more expensive than dry formulas for two reasons. Firstly, operating costs are increased due to the freight associated with heavier liquid feeds. Secondly, capital costs are increased because the additional inputs require more equipment to inject the fertilizers into the feed solution (e.g. additional dosing channels in fertigation equipment.) In most cases, it is unclear if these formulas have been rigorously tested or optimized. In general, fertilizer companies that market solely to cannabis growers often have outrageously high margins. Fertilizer companies that also deal with the broader horticulture industry provide very similar products at a fraction of the cost. Many cannabis-targeted fertilizer companies also over-formulate their recipes, delivering more nutrients than plants can absorb, particularly P. Over-formulation causes numerous problems including overcharging on nutrients that end up running off and going down the drain, water pollution from unnecessary runoff, and damaging salt build-up in the growing media.

> **FERTILIZER COMPANIES THAT ALSO DEAL WITH THE BROADER HORTICULTURE INDUSTRY PROVIDE VERY SIMILAR PRODUCTS AT A FRACTION OF THE COST.**

Alternatively, growers can blend their own fertilizer mixes from raw mineral salts. The main advantages to blending your own salts are reduced cost and being able to customize and fine-tune the mixture. Creating a custom nutrient formula requires expertise and may call for over a dozen components but many fertilizer companies can also make custom mixes for a minimal fee. Blends from raw salts are often many times less expensive than fertilizers marketed to cannabis growers.

ORGANICS

Nutrients delivered from organic sources present unique advantages and challenges. Regardless of the source, plants absorb nutrients in inorganic forms so organic materials must be converted to an inorganic form by microorganisms in the soil to become available to plants. The dynamics of microbial nutrient cycling are controlled by environmental factors, soil chemistry and biology and the composition of the source material. Considering all the factors affecting the availability of nutrients from organic sources it is more difficult to develop a precise nutrient regime with organic fertilizers. Moreover, the biochemical reactions to convert organic sources to plant-available nutrients can affect the chemistry of the root zone. Organic nutrient sources offer the benefits of enriching root zone biology and releasing slowly over time. Using an organic system can also improve marketability of final products.

RATE AND RATIOS

Once flowering is triggered, cannabis grows and develops very quickly. To meet the changing needs of a crop, nutrition must match each developmental stage. While the science behind the precise nutritional needs of cannabis is still in its infancy and is cultivar dependent, we can look to a few different trends from reputable commercial formulas and the available research (Table 2).

In the vegetative stage, plants build structure and size and require steady supply of N, and calcium balanced with the other essential nutrients. A recent investigation found 160 ppm N during the vegetative stage is optimal with N uptake efficiency reducing at higher concentrations and deficiencies showing below 75 ppm N [2]. For P, they found an optimal rate between 15-30 ppm [3] and they found K uptake to be cultivar dependent and range between 175-240 ppm [4]. Alternatively, another study found the optimal rate of N during the vegetative stage was close to 400 ppm [5].

During the transition from vegetative to flowering, plants begin to stretch and grow rapidly, requiring a higher rate of balanced fertilizer. As flowering progresses, P and K become more important for flower development. A recent study showed that increasing fertilizer P concentration up to a consistent rate of 90 ppm increased flower yields but diluted THC above 30 ppm so there are optimal rates of P which balance yield and potency [6]. Others suggest a high rate of P for about a week after flower initiation [1]. The latest research suggests N rates during flower between 160 ppm [7] to around 250 ppm, with higher concentrations increasing yield but diluting THC [8].

As plants finish their lifecycle toward the end of flower, metabolism slows and nutritional needs decline. There is an ongoing debate about the need for flushing at the end of flowers. Some argue nitrates or other compounds negatively affect the smoke and flavor of flower and flushing the media at the end of flower reduces those compounds. Alternatively, plant metabolism continues to harvest and requires nutrients to function properly.

Optimum rates will also depend on the environment in which plants are grown. Plants driven in a more intense environment that drives more photosynthesis or transpiration with brighter lights or greater vapor pressure deficit will have greater nutritional needs than those grown in a gentler environment.

KEY TAKEAWAYS

- There are so many factors affecting nutrient availability that simply applying the right amount of each nutrient is not enough. The fertilizer formulation and growing system all need to work together to allow crops to access the nutrient they need when they need them
- Growth and yield are limited by the most limiting factor, so all nutrients need to be optimized and the lack of just one nutrient can seriously limit yields
- Recipes from many cannabis-targeted fertilizer lines over-apply nutrients, so many common practices in legacy growing (e.g., flushing, etc.) likely just alleviate salt stress caused by over application.
- Nutrient use and needs are affected by plant growth stage and intensity of growing systems, so fertilizer rates much change accordingly.

TABLE 1. Characteristics of essential plant nutrients.

NUTRIENT	MAIN ROLES	DEFICIENCY SYMPTIOMS [9]	MOBILITY IN PLANT	AVAILABLE ION(S)	COMMON CHEMICAL SOURCES	COMMON ORGANIC SOURCES
Nitrogen	Key component of amino acids/ protiens	Reduced growth, chlorosis starting with lower leaves and quickly progressing to whole plant	Mobile	NO_3^-, NH_4^+	Ammonium nitrate, calcium nitrate, potassium nitrate	Composted manure, blood meal, feather meal, fish emulsion, cottonseed meal, soybean meal
Phosphorus	Part of genetic matreial, cell membranes and cellular energy...	Purpling of leaves starting with lower growth. Newer research shows cannabis has symptom of olive-green spotting developing to necrotic spots on lower leaves	Somewhat Mobile	$H_2PO_4^-$, HPO_4^{-2}	phosphoric acid, monopotassium phosphate, monoammonium phosphate, potassium chloride	Rock phosphate, composted manure, bone meal
Potassium	Metabolism, water regulation, intercellular signaling, stress response	Chlorosis on older leaves starting toward the edges and progressing toward midvein. Tip and leave edge burn	Very Mobile	K^+	Potassium nitrate, potassium bicarbonate, monopotassium phosphate	Green sand, Kainite, composted manure, kelp, wood ash, langbenite
Sulfur	Protein production and photosynthesis	Reduced growth, bright yellow chlorosis starting at the base of lower leaves and progressing to whole leaves and plant	Immobile	SO_4^{+2}	Sulferic acid, magnesium sulfate, calcium sulfate, ammonium sulfate	Composted manure, langbenite, gypsum
Magnesium	Core of chlorophyll molecule	Chlorosis along leaf veins of older leaves progressing toward leaf edges. Advances to necrotic spots between veins along midvein	Somewhat Mobile	Mg^{+2}	Magnesium nitrate, magnesium sulfate (epsom salt)	Langbenite, gypsum, dolomitic lime
Calcium	Structural component of cell walls and is used to communicate stress signals throughout the plant.	Slowed growth, chlorosis progressing to necrosis on new growth. In advanced cases, growing tips can die, causing prolific branacing of stunted shoots.	Immobile	Ca^{+2}	Calcium nitrate	Bonemeal, dolomitic lime, calcitic lime
Iron	Various metabolic processes. Chlorophyl synthesis and maintainance	Chlorosis of leaf edges on new growth progressing to interveinal chlorosis on new growth	Immobile	Fe^{+2}, Fe^{+3}	Iron chelates, iron sulfate	Organic fertilizer blends with good balances of macronutrients and secondary nutrients typically also contain micronutrients in sufficient quantities. It is more difficult to fine-tune application of specific micronutrients in organic systems
Boron	Cell development	Stunted, distorted new growth. Smaller, narrower leaves. Progresses to severe stunting and death of growing tips	Immobile	H_3BO_3, $H_2BO_3^-$	Boric acid, borax	
Manganese	Water-splitting step of photosynthesis	Interveinal chlorosis in newer growth progressing to tan interveinal necrotic spots	Immobile	Mn^{2+}	Manganese chelates, manganese sulfate	
Zinc	Enzymatic activity to produce carbohydrates, proteins, and chlorophyll	Chlorosis of leaf edges on new growth progressing to tan necrosis on edges of new leaves	Immobile	Zn^{2+}	Zinc chelates, zin sulfate	
Molybdenum	Nitrogen metabolism		Immobile	MoO_4^{-2}	Sodium molybdate, ammonium molybdate	
Copper	Metabolic energy transfer	Stunting, distortion and interveinal chlorosis of newer growth	Immobile	Cu^{+2}	Copper chelates, copper sulfates	
Chlorine	Balancing electrical charge and osmotic balance		Mobile	Cl^-	Natural impurities in fertiliers and source water	
Nickel	Nitrogen metabolism	Yellowing of older leaves progressing to burning of tips and edges	Mobile	Ni^{2+}	Nickel chelates, nickel sulfate	

TABLE 2.

Recommended ranges for cannabis fertilizers at various growth stages. These ranges are intended as very general guidelines as rates will vary greatly due to different growing systems and environments. Rates are based on analysis of various reputable commercial formulas.

CANNABIS FERTILIZERS	VEG	EARLY FLOWER	MID FLOWER	LATE FLOWER
Nitrogen, ppm	75-200	100-200	100-200	75-100
Nitrate:Ammonium ratio	20-50	10-20	20-50	10-20
N-P-K ratio	9-2-10	10-5-10	8-2-10	7-2-10
Calcium:Magnesium Ratio	2-5	3-5	2-4	2-4

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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