WHITEPAPER

THE GREAT DEBATE

SYNTHETIC VS. ORGANIC PLANT NUTRIENTS

RX GREEN TECHNOLOGIES

Plant nutrients are inorganic elements such as zinc or magnesium that are absorbed by plant roots in order to fuel growth and development. Most of the nutrients required for plant growth are already present in traditional soil, although not always in the required volume or form. In contrast, given the use of inert media, hydroponic farming requires that all nutrient application and management come from external sources. Regardless of cultivation media, most cultivators will apply some additional level of nutrition to ensure optimal plant outcomes. For the purpose of this paper, nutritional inputs will be classified as fertilizers. Finding the proper source for nutritional inputs, and whether they qualify as "organic" or "inorganic / synthetic", is currently a subject hotly debated in the cannabis community. Our purpose here is to provide explanations and education to ensure this debate leads to informed decision making across cultivators and their end-consumers.

SOIL NUTRIENTS

There are 17 essential minerals required by plants to grow; three of those are supplied through air and water (carbon, hydrogen and oxygen). The other 14 must either be available in the soil or water or added as a supplement. There are also several nutrients that are considered non-essential, meaning plants will grow without deficiencies if these elements are not present, but they are considered beneficial to enhanced plant growth.

Table 1. Plant Nutrients

Nutrients From Air & Water	Nutrients From Soil and Added Supplements			
	Primary Macronutrients	Secondary Macronutrients	Micronutrients	Non-Essential Nutrients
Carbon (C)	Nitrogen (N)	Calcium (C)	Boron (B)	Aluminum (Al)
			Chlorine (Cl)	
Hydrogen (H)	Potassium (K)	Magnesium (Mg)	Copper (Cu)	Cobalt (Co)
			Iron (Fe)	
			Manganese (Mn)	Selenium (Se)
Oxygen (O)	Phosphorus (P)	Sulfur (S)	Molybdenum (Mo)	Silicon (Si)
			Nickel (Ni)	
			Zinc (Zn)	Sodium (Na)

NITROGEN: Nitrogen (N) is the most important nutrient in the plant growth cycle. It is an essential element in chlorophyll, the green molecule that plays a major role in photosynthesis. All N in fertilizers originates from atmospheric N gas, or N_2. This can be converted into ammonia in fertilizer factories, and is also converted to ammonium by microorganisms in the soil. Many animal-based nitrogen sources, such as guano, are not water soluble and require further microbial breakdown to provide available N to the plant. Plants use N in the form of nitrate or ammonium.

PHOSPHORUS: Phosphorus (P) is the fuel source for the plant's metabolism and vital for photosynthesis. The phosphate in fertilizers is either fully water soluble or partly water soluble and partly citrate soluble, both of which are considered plant available. Citrate-soluble P dissolves slowly and is relatively more effective in acidic soils. The concentration of P (usually indicated as percent P_2O_5) refers either to the available or the total portion of phosphate. Phosphate rock (PR) is a naturally occurring source of P, which can then be processed with acid to yield superphosphate, a highly available and soluble source of P commonly used in manufactured fertilizers. PR can be used directly as a fertilizer, but only provides about half the available P as the superphosphates. Diluted phosphoric acid is also a common P source for use in hydroponics.

POTASSIUM: Potassium (K) is essential for photosynthesis and enzyme reactions. Potash, a.k.a. potassium, fertilizers are predominantly water-soluble salts. Raw K salts can be found in seawater (or left behind as seawater evaporates) as a major component of rock salt formations in ocean basins. Raw potassium salts are combined with a variety of other salts by various methods of heating, cooling, and chemical reactions with acids to produce fertilizers.

CALCIUM: Calcium (Ca) is a major component of plant cell walls and assists with transporting other plant-essential minerals. There is no shortage of raw materials for Ca fertilizers as whole mountains consist of naturally occurring calcium carbonate ($CaCO_3$). Ca is also found in gypsum either as a mineral or as a by-product of wet-process phosphoric acid production. Calcium nitrate is a synthetic compound that provides a good source of nitrate N and water-soluble Ca and is especially useful for fertilizing horticultural crops.

Table 2. Micronutrient Function in Plants

Element	Function in Plant
B	Important in sugar transport, cell division, and amino acid production
Cl	Used in turgor regulation, resisting diseases and photosynthesis reactions
Cu	Component of enzymes, involved in photosynthesis
Fe	Component of enzymes, essential for chlorophyll synthesis, photosynthesis
Mo	Involved in nitrogen metabolism, essential in nitrogen fixation by legumes
Mn	Chloroplast production, cofactor in many plant reactions, activates enzymes
Zn	Component of many enzymes, essential for plant hormone balance and auxin activity

MAGNESIUM: Magnesium (Mg) is part of the chlorophyll molecule and is also important for key plant enzyme functions. Natural reserves of Mg are very large, both in salt deposits and in mountains consisting of dolomitic limestone. Mg fertilizers are grouped by water soluble and water insoluble classifications. Among the soluble fertilizers are magnesium sulfates and magnesium chelates. Among the insoluble or partially water-soluble sources are magnesium oxide, magnesium carbonate and magnesium silicate. The insoluble or partially soluble materials are frequently used as liming materials for soil pH correction rather than as fertilizers.

SULFUR: Sulfur (S) is an important part of protein synthesis, enzyme development and compounds involved in cold tolerance. Most S-containing fertilizers are in fact sulfate salts of compounds that also contain other major nutrients or micronutrients, such as magnesium sulfate or copper sulfate. The only truly single-nutrient S fertilizers are elemental S products. Pure elemental S has to first be oxidized to sulfate in the soil by bacteria before it can be absorbed by plant roots.

TRACE ELEMENTS: Trace elements, or micronutrients, play vital roles in plant metabolism and photosynthesis. In hydroponic media, multiple micronutrient fertilizers are required. In traditional soil farming, slow-release micronutrient fertilizers that can provide a continuous supply without toxicities are required. Such fertilizers, with several or all micronutrients, are generally partly water soluble and have slow-acting components. Many of the naturally occurring and minimally refined micronutrient sources rely on oxidation by soil bacteria to convert into plant-available, ionic forms.

IONIC ELEMENTS

In order to understand the difference between organic and inorganic ("synthetic" in industry-terms) plant nutrition inputs, it is important to first understand that plants can only absorb nutrients in their ionic form. Ions are elements found on the periodic table that carry either a negative or positive charge depending on the total electrons hanging on to it. A negatively charged ion is called an anion, and a positively charged ion is called a cation. Due to the laws of attraction, anions and cations are attracted to each other when they are together, which leads them to form ionic compounds.

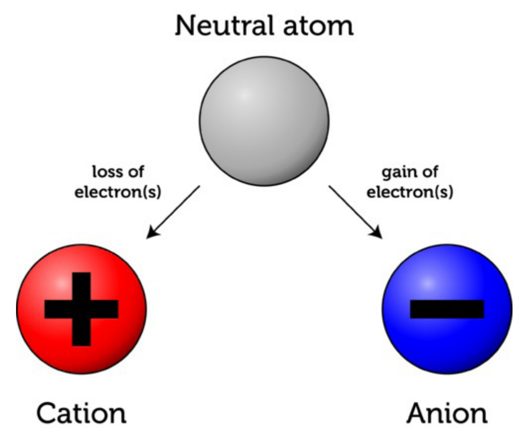

Figure 1: Cations and Anions

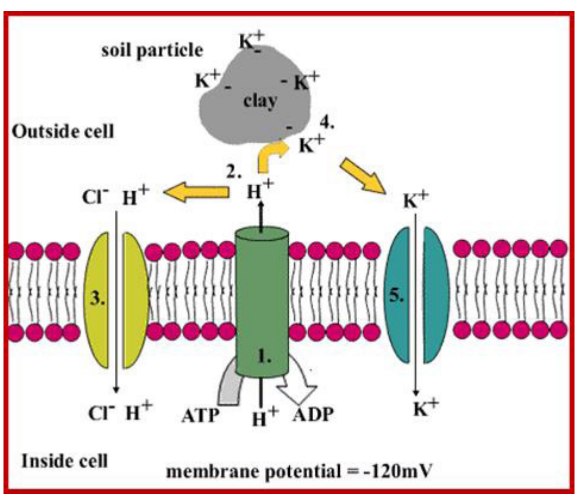

Figure 2: Absorption of Ions

Ionic compounds made from mineral nutrients are commonly used in synthetic fertilizer blends as a readily available source of food for plants. These are often referred to as mineral salts, not to be confused with table salt, or sodium chloride. Salts, by their chemical definition, are "any chemical compound formed from the reaction of an acid with a base, with all or part of the hydrogen of the acid replaced by a metal or other cation."

Mineral salts dissociate, or break apart, in water to reveal their ionic nutrients. Calcium nitrate and potassium phosphate are some of the ionic compounds you may recognize as plant nutrients. Plant roots then absorb the dissociated mineral salts as ions. Organic fertilizers can be broken down by soil organisms over time to reveal their ionic, plant-available elements. Plants do not know the difference between organic and inorganic inputs, as they only use nutrients that are available in their inorganic, ionic form. Plants use these inorganic nutrients to make necessary metabolites, such as amino acids, simple sugars and other organic compounds.

SOIL BIOLOGY

Organic fertilizers rely on the mineralization process to release their plant-available source of nutrients. Soil has a complex and elaborate ecology consisting of bacteria, fungi, protozoa and insects. These organisms use the larger organic compounds found naturally in soil and organic amendments as a source of food. When these organisms "eat" the organic material, the breakdown of the material releases ions that plants can use as food (hence "mineralization"). Plant roots will then take up these minerals as needed, or as they become available. The length of time required for full mineralization varies based on the soil environment, microbial species found in the soil and the specific mineral compounds contained in the fertilizer; full nutrient availability may take years after application. Balancing soil amendment applications based on soil analysis test results, combined with sustainable farming practices such as low till and cover cropping, can provide long-term, adequate soil fertility.

GROWING WITHOUT SOIL

In the world of indoor and greenhouse growing, the efficiency of soil organisms to feed plants cannot be relied upon. The time it takes for organic compounds to break down and provide plant-available nutrition is not often available to soilless farmers.

Soilless substrates contain very little, if any, of the plant-essential nutrients. Therefore, these substrates require complete fertilizers that provide the full spectrum of macro and micronutrients, preferably in a water-soluble form. The correct balance of nutrients must be added in the early vegetative growth stage in order to prevent deficiencies from limiting growth and yields.

ORGANIC DEFINITION AND SOURCING

The simple definition of organic is "consisting of or derived from living matter." According to the National Organic Program (NOP), "organic is a labeling term for food or other agricultural products that have been produced using cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity in accordance with the USDA organic regulations. This means that organic operations must maintain or enhance soil and water quality, while also conserving wetlands, woodlands, and wildlife."

Soil organic matter refers to all parts that are of biological origin including decomposing plant material and animal wastes, soil microorganisms and the substances synthesized by the soil microbiome. Organic matter contributes to pools of plant available nutrients through gradual breakdown of materials. If relying entirely on organic matter in soil for nutrients, plants may not receive enough nutrition to provide optimal yields and quality. This is where soil amendments, or fertilizers, play an important role.

Raw materials for organic fertilizers are generally sourced from animal manures, animal by-products, rural and urban human waste, compost and crop residues. Animal by-products include fresh or composted manure, worm castings, bat guano, bone meal, feather meal and fish meal. Plant-derived amendments include kelp meal, alfalfa meal and soybean meal. Town/urban compost is made from industrial waste, city garbage, sewage sludge, etc. Rural compost is made from straw, leaves, livestock bedding and manure, animal rendering material, plant waste material, etc.

Table 3. Nutrient Content of Manure and Composts

Average nutrient content of bulky organic manures and composts

Type of manure	N	P_2O_5	K_2O
		(%)	
Cattle dung	0.3	0.10	0.15
Sheep/goat dung	0.65	0.5	0.03
Human excreta	1.2-1.5	0.8	0.5
Hair and wool waste	12.3	0.1	0.3
Farmyard manure	0.5	0.15	0.5
Poultry manure	2.87	2.90	2.35
Town/urban compost	1.5	1.0	1.5
Rural compost	0.5	0.2	0.5

Livestock manures contain N, P and K, but only a fraction of the total nutrient content is plant-available. A variety of synthetic substances including inorganic, mineral fertilizers are also approved for use in organic production when they are not available as a naturally-occurring substance. Mined minerals include gypsum, humates, rock phosphate and potassium sulfate. Acceptable synthetic, or manufactured, materials include vitamins and certain micronutrients.

INORGANIC DEFINITION AND SOURCING

The definition of inorganic is the opposite of organic: "not consisting of or derived from living matter." Inorganic, synthetic or mineral are collective terms used to describe fertilizer that is not derived from living or biological matter. Minerals can still be considered a natural input, while synthetic fertilizers contain minerals that are modified during manufacturing to produce a finished, more effective product. These modifications are essential to create a product that has greater solubility, stability, and plant-uptake efficiency.

The use of inorganic fertilizers has advantages in the cannabis industry depending on the management and cultivation style used. Indoor and greenhouse space, when growing in containers, will benefit greatly from the use of mineral-based fertilizers due to the high level of nutrient availability from this type of fertilization. Fast-growing annuals require rapid nutrition, and the ionic form of elements provided by mineral nutrients delivers exactly that.

The source of raw materials can make a difference, especially when growing cannabis. We know that cannabis is an accumulator of heavy metals, which means that it can absorb and retain toxins from its growing environment at much higher levels than other plant species. Cheap, industrial grade minerals may be contaminated with high levels of toxic heavy metals, such as cadmium or mercury. Further processing to a higher-quality grade, such as pharmaceutical grade, will greatly reduce or eliminate (depending on the process) the levels of these contaminants, ensuring safe end-consumer use.

COMPARISON OF INPUTS

Traditional organic inputs, typically supplied as raw minerals, compost and manures, can be difficult to rely on and may not supply adequate plant nutrition. The nutrient availability of organic sources is widely varied, and only provides minimal availability in the first year of application. Compost and manures yield as little as 3% of the available N in the first year[i]. That said, excessive inorganic fertilizer application may be harmful to the diversity of soil organisms and overall soil structure. Combining resource inputs can potentially produce optimal results, especially if growing outdoors in soil. The soil fertility enhancement offered by organic inputs, such as compost or manures, coupled with the precise nutrient delivery of inorganic components, can provide the best long-term results.

The Journal of Agronomy published research findings that soils treated with inorganic fertilizers vs. organic fertilizers still had higher levels of organic carbon, N, P, K, bacteria and fungi than soils that were untreated[ii]. In fact, the nutrient levels were higher than in the organic plots, and the biological organisms were higher than the untreated plots. This implies that, in contrast to popular belief, inorganic fertilizers do not kill organisms, and in fact offer an additional food source for soil biology and further contribute to soil fertility.

The addition of mineral fertilizers to compost and even to manures can increase the effect of these amendments on organic C and N content in soil and soil enzyme activity[iii]. Complete nutrient fertilizer applications may take care of existing nutrient deficiencies when applied at the correct time in the plant's life cycle. In the absence of having the ability to test soil every week for nutrient status, applying inorganic fertilizers throughout the crop cycle is a reasonable alternative to assure optimal yield and quality.

SUMMARY

Organic materials can greatly increase soil fertility and improve soil ecology, while inorganic amendments provide a readily available source of nutrition for plants. Combining nutrient sources can often provide optimal outcomes for both crop yields and soil ecology[iv].

Plants in a recirculating hydroponic, soilless or container garden will see the most benefit from using mineral nutrients, as it is difficult to maintain positive microbial life in these environments. If plants require only one or a few elements right away, a synthetic fertilizer will provide it quickly. If you are using a fertigation or automated irrigation system, water-soluble nutrients are mandatory.

Growing outdoors in field soil will see the most benefit from using organic nutrients. This is where the microbes are at their best, working with organic compounds from soil amendments and insoluble minerals naturally occurring in the soil. The nutrients can break down slowly and feed the plant as it needs it. Inorganic amendments can provide additional nutrition, and when applied conservatively, will not harm soil organisms and should correct any potential nutrient deficiencies.

Table 4. Comparison of Inputs

Chemical Fertilizer vs Organic Fertilizer Comparison Chart

	Chemical Fertilizer	Organic Fertilizer
Example	Ammonium sulfate, super phosphates, ammonium nitrate, urea, ammonium chloride, etc.	Cottonseed meal, blood meal, fish emulsion, manure and sewage sludge, etc.
Advantages	Chemical fertilizers contain the three primary macronutrients that provide an immediate supply of nutrients; may also contain secondary macronutrients and trace minerals.	Adds natural nutrients to soil, increases soil organic matter, improves soil structure, improves water holding capacity, reduces soil crusting problems, provides slow release of nutrients
Disadvantages	Several chemical fertilizers have high acid content. They have the ability to burn the skin. Changes soil fertility.	Have slow release capability; distribution of nutrients in organic fertilizers is not equal
Rate of Production	Immediate supply or slow release.	Slow release only.
About	Chemical fertilizers are manufactured from synthetic or inorganic material.	Organic fertilizers are made from materials derived from living things or inorganic minerals.
Nutrients	Have equal distribution of three essential nutrients: phosphorus, nitrogen, potassium.	Have unequal distribution of essential nutrients.
Cost	Chemical fertilizers turn out to be cheaper because they pack more nutrients per pound of weight.	Organic fertilizer may be cheaper per pound but works out to be more expensive over all because more of it is needed for the same level of nutrients.

SUGGESTED READING

Roy, R. N. (2007). Plant nutrition for food security: A guide for integrated nutrient management. New Delhi: Discovery Publishing House.

Lowenfels, J., & Lewis, W. (2016). Teaming with microbes: The organic gardeners guide to the soil food web. Portland, Or.: Timber Press.

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[i] Ozores-Hampton, M. (2012). Developing a Vegetable Fertility Program Using Organic Amendments and Inorganic Fertilizers. HortTechnology,22(6), 743-750.

[ii] Nakhro, N., & Dkhar, M. (2010). Impact of Organic and Inorganic Fertilizers on Microbial Populations and Biomass Carbon in Paddy Field Soil. Journal of Agronomy, 9(3), 102-110.

[iii] Šimon, T., & Czakó, A. (2018). Influence of long-term application of organic and inorganic fertilizers on soil properties. Plant, Soil and Environment, 60(No. 7), 314-319.

[iv] Ozores-Hampton, M. (2012). Developing a Vegetable Fertility Program Using Organic Amendments and Inorganic Fertilizers. HortTechnology,22(6), 743-750.

Table 1
Adapted from various sources

Table 2
Adapted from www.pioneer.com

Table 3
Food and Agriculture Organization of the United Nations
www.fao.org

Table 4
Adapted from various sources

Figure 1
https://www.quora.com

Figure 2
http://plantcellbiology.masters.grkraj.org