by Andrew Taylor,
Chemist Flairform Australia

CHOOSING HYDROPONIC NUTRIENTS

PART 1: ESSENTIAL NUTRIENTS AND NUTRIENT BALANCE

Misleading claims and misinformation concerning hydroponic nutrients make it difficult to distinguish fact from marketing hype.

The purpose of this article is to provide a basic understanding of the key factors concerning plants and nutrients, which are

- the essential nutrients,
- nutrient balance,
- overall nutrient concentration,
- pH buffering capacity,
- ease of use,
- solubility.

When considered together, these factors allow meaningful comparison of different brands and empower growers to make knowledgeable choices. The first two will be discussed here, and the remainder will be discussed in Part 2, which will appear in the next issue of Maximum Yield.

THE ESSENTIAL NUTRIENTS

Each nutrient species has a specific role in plant growth. If one is missing or in short supply, the effectiveness of others is reduced and growth will suffer. For example, magnesium and nitrogen are necessary in the production of chlorophyll. However, if magnesium is lacking, an oversupply of nitrogen will not compensate for the undersupply of magnesium. This principle is known as the "law of limiting factors."

Successful growth requires that

- all nutrient elements are provided,
- the correct species of these nutrient elements are provided,
- the correct nutrient management is provided to ensure all species are available for root uptake.

Ingredients

Plant growth depends upon a combination of nutrients being available and in sufficient quantity (see Table 1). The six macronutrients are those needed in the largest quantities. Of these the most important are the NPK fertilizers — nitrogen (N), phosphorus (P), and potassium (K). The micronutrients are also needed but only in small amounts.

Generally speaking, nutrients can only be rapidly absorbed by plant roots if they are in the form of mineral "ions" (as illustrated in the second column of Table 1). An ion is an atom or group of atoms that has gained or lost one or more electrons and, therefore, carries a positive or negative charge. This electrical charge enables ions to either repel or attract other ions. Ions with a positive charge (+) are called "cations" and those with a negative charge (–) are called "anions." Because opposite charges attract they are able to exchange places on a root hair that carries the opposite charge. In this way nutrients are brought close to root hairs so they can be readily absorbed.

Inorganic nutrients or salts supply nutrients in the mineral ion form and, provided pH is within the acceptable range, are readily available for root uptake. Some common sources are shown in the ingredients column of Table 1. These will often be listed in the derivation statement on nutrient labels.

Note the use of chelated ingredients (e.g., EDTA, EDDHA) for several of the trace elements. Chelates are organic compounds that react with metal ions to form water-soluble complexes. Although it is standard practice to employ chelates for iron, they are not always employed for copper, manganese, and zinc. This is a risky practice because these elements can be very unstable at the higher pH values that nutrient solutions can experience, even for short time periods.

Some Common/Undesirable Nutrient Species in Concentrated Nutrient Formulations

Organic nutrients: Pure organic sources (e.g., manure, humic acids, seaweed, guano) essentially contain only the macronutrients nitrogen and phosphorus and trace elements in an organic form. These uncharged, non-ionic molecules first need to be decomposed to release the mineral forms of the nutrients before they can be absorbed by the roots. This takes time and the action of micro-organisms that are generally not present in hydroponics. They are, therefore, slow to act and give variable results. Note that pure organic fertilizers, by definition, would have very low EC (conductivity) values. Hence, EC is an effective analytical tool for verifying the "100% organic" claim.

Organic species are important in soil culture because organic and inorganic species can interact to assist plant nutrition. Although inorganics provide the nutrition, organics can increase their effectiveness due to their ability to increase the cation exchange capacity (CEC) of the soil. CEC is a soil's ability to retain an inorganic species and to prevent them from being washed away. CEC is particularly poor in soils composed largely of sand. Therefore, the distribution of organic matter (e.g., compost) throughout the soil profile will help increase nutrient retention. Note that CEC is increased by any organic matter and that it does not need to be organic nutrients.

Table 1:

Essential Nutrients Supplied by Liquid Hydroponic Fertilizers

Element	Species required for plant uptake	Some commonly used ingredients	Typical minimum concentration (ppm)**	
Macronutrients			**Grow**	**Bloom**
Nitrogen (N)	Nitrate (NO_3^-)	potassium nitrate, calcium nitrate, magnesium nitrate, ammonium nitrate	160	130
Phosphorus (P)	Phosphate ($H_2PO_4^-$)	Mono-potassium phosphate, mono-ammonium phosphate	30	60
Potassium (K)	Potassium (K^+)	potassium nitrate, potassium sulfate	230	300
Calcium (Ca)	Calcium (Ca^{2+})	calcium nitrate	100	80
Magnesium (Mg)	Magnesium (Mg^{2+})	magnesium sulfate, magnesium nitrate	30	30
Sulfur (S)	Sulfate (SO_4^{2-})	potassium sulfate, magnesium sulfate	60	60
Trace Elements				
Iron (Fe)	Iron (Fe^{3+})	Iron EDTA, iron EDDHA	2.0	2.0
Copper (Cu)	Copper (Cu^{2+})	Copper EDTA	0.05	0.05
Manganese (Mn)	Manganese (Mn^{2+})	Manganese EDTA	0.5	0.5
Zinc (Zn)	Zinc (Zn^{2+})	Zinc EDTA	0.1	0.1
Molybdenum (Mo)	Molybdate (MoO_4^{2-})	Sodium molybdate	0.05	0.05
Boron (B)	Borate ($H_2BO_3^-$)	Borax	0.2	0.2

** Typical minimum concentration of elements available in high-quality, general-purpose hydroponic formulations during both the growth and bloom phase (i.e., EC ~2.0 mS)

In hydroponic systems CEC is unnecessary because the root zone is frequently replenished with nutrients. This is why substrates of essentially zero CEC (e.g., rockwool, perlite, clay pebbles) are perfectly suitable.

Ammonium: Ammonium concentration should represent no more than ~20% of the required total nitrogen concentration.

An excess can cause damage to roots and stem bases, particularly in younger plants, which results in poor growth and yield. It is generally accepted that plants will not take up nitrogen in the ammonium (NH4+) form and that it must first be oxidized into nitrate (NO3-).

Chloride: Excess chloride will typically cause chlorosis (leaf yellowing), which also results in poor growth and yield. Potassium is sometimes supplied as potassium chloride and this should be avoided.

Overview: The Essential Nutrients

Check the label to ensure that the nutrient product contains the full suite of macronutrients (*see Table 1*). (Note: For reasons discussed later, trace elements might not be declared on the label.) To ensure rapid availability to roots, confirm the nutrients are supplied using inorganic nutrients and not organics (*as per the ingredients column in Table 1*).

NUTRIENT BALANCE

A balanced suite of the essential nutrients (*as specified in Table 1*) can be incorporated into either a 1-part, 2-part, or 3-part package.

2- and 3-Part Nutrients

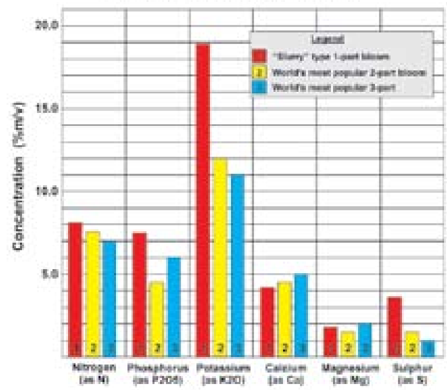
Most 2- and 3-part brands provide adequate levels of macronutrients and trace elements. The 2- or 3-part packaging format is often deemed necessary by manufacturers to avoid stability and compatibility problems between certain nutrient species when they are present in the same bottle. As such, the nutrients are strategically distributed among each part. Most important, the calcium is kept separate from the sulfate and phosphate (i.e., in a 2-part, calcium is normally in part 'A', whereas sulfate and phosphate are in part 'B'.)

1-Part Nutrients

As indicated in Graph 1, when created in the form of a slurry, a 1-part product is actually able to provide superior levels of macronutrients compared to 2- and 3-part nutrients.

1-parts not based on slurry technology, however, are typically deficient in at least one macronutrient. This is due to the difficulty of formulating a product with

Graph 1. Relative nutrient concentration of a 1, 2 and 3-part bloom nutrient



concentration equivalent to 2- and 3-part nutrients while still providing a complete balance of all necessary macronutrients. The main problem is accommodating sulfur (as sulfate), because in meaningful quantities a precipitate will always form (see Fig 1). This is due to calcium's affinity for sulfate, which results in a precipitate of calcium sulfate, (CaSO4). (Note that in 2- and 3-part products, calcium and sulfate are kept in separate bottles.) The 1-part precipitate is usually in the form of either a heavy sludge that cannot be homogenized

Fig 1.

Fig 2.

to enable a blended dose to be poured, or a crystalline precipitate that can be neither homogenized nor easily dissolved.

To avoid the sludge or crystalline precipitate, most 1-part manufacturers either eliminate all sulfate from the formulation or reduce the overall nutrient concentration, particularly the calcium.

Slurry

As mentioned, all of these problems can be overcome by employing slurry technology. The slurry is a suspension (of mainly $CaSO_4$ solid) within a solution containing the balance of necessary macronutrients and trace elements. It is shaken just prior to use and remains homogenized (i.e., blended) for sufficient time to dispense a uniform dose (see Fig 2). Once the dose is added to water and briefly stirred, the $CaSO_4$ suspension dissolves immediately. The use of a slurry therefore enables the nutrient manufacturer to exploit the solubility limits of calcium and sulfate and to actually squeeze more nutrient species into a given volume than what is possible with the standard solution technology used in 2- and 3-parts. This type of 1-part nutrient product is represented in Graph 1.

Trace Elements

Mention of trace elements is often excluded on labels (especially 1-parts) simply because their concentration usually falls below the minimum reporting threshold imposed by certain jurisdictions.

How to Read Nutrient Label Analyses (i.e., "Guaranteed Analysis")

With the common exception of potassium and phosphorus, most nutrient labels state the concentration of nutrient species in their elemental form — the "Element" column in Table 1.

K_2O and P_2O_5: By convention, many labels represent potassium (K) as dipotassium oxide (K_2O). To convert K_2O to K, multiply the K_2O figure by 0.83. Similarly, phosphorus (P) is often represented as phosphorus pentoxide (P_2O_5). To convert P_2O_5 to P, multiply the P_2O_5 figure by 0.44.

Concentration: The concentration of elements are represented as a percentage (%). Specifically, this is %m/v (i.e., percentage mass per unit of volume). Multiplying this figure by 10 gives the

concentration in grams per liter or g/L. Thus, 3.0% equals 30 g/L. Alternatively, multiplication by 10,000 derives the concentration in ppm (parts per million) or mg/L. Here, 3.0% equals 30,000 ppm.

How to Compare Nutrient Label Analyses of 1-, 2-, and 3-Part Labels

Label analysis figures for 2- and 3-part nutrients are usually based upon the concentration of nutrients in the individual packs. Therefore, in order to make a meaningful comparison between a 2-part and 1-part nutrient, it is necessary to first double the figures quoted on the 1-part. This ensures we are comparing the contents of equal volumes, for example, 2 x 1L bottles of the 1-part with 2 x 1L bottles ('A' and 'B') of the 2-part.

Obviously, to compare a 1-part with a 3-part we would triple the 1-part figures, and to compare a 2-part with a 3-part, we would halve the 2-part figures before multiplying them by 3.

Using this information we are able to meaningfully compare analyses. For instance, in Graph 1 we are able to make a meaningful comparison between 1-, 2- and 3-part nutrients.

Concentration of Specific Nutrient Elements Yielded by a Given Dose

To determine specific nutrients by dose, the individual analysis specification should be converted into ppm (or mg/L) and then multiplied by the dose rate per liter. For example, if part 'B' of a 2-part contains 3.0% phosphate as P2O5, then when this part is used at 4 mL per liter it will yield 53 ppm phosphorus as P. That is,

Step 1. "3.0% P2O5" = 30,000 ppm as P2O5 (i.e., 3.0% x 10,000).

Step 2. Convert this figure to P: 30,000 ppm as P2O5 = 13,200 ppm as P (30,000 ppm x 0.44).

Step 3. 4 mL per liter yields 53 ppm P (i.e., 13,200 ppm x 4 mL/1,000 mL).

Overview: Nutrient balance

Using the information above, we can compare the macronutrient content of different brands, whether 1-, 2-, or 3-part. Further, we can verify whether or not the typical minimum concentrations are met by checking the analysis against the right hand column of Table 1.