NUTRIENTS FOR HYDROPONICS

and tissue culture

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PREFACE

Plants naturally grow in soil, but modern science has found other ways for them to grow.

Once you understand what things soil does for plants, you can then with the help of modern science begin to conceive other ways of doing those things, replacing the need for soil.

The main thing soil does for a plant is to provide nutrients. It also provides a place for the roots to anchor the plant, and an environment to insulate the roots from extreme weather and provide moisture and oxygen for the roots to absorb.

Hydroponics and tissue culture are modern ways of growing plants without soil. They offer the grower many advantages, not the least an ability to have greater control over how the plant grows.

Pivotal to that control, is to understand and manage the nutrients provided to the plant. This management of nutrients is what this book is about.

CHAPTER 1 INTRODUCTION

Plants, like any living thing, need food to grow. In nature, such plant food comes from the soil. If we grow a plant using tissue culture or hydroponics, there is no soil as such, meaning the nutrients must be supplied artificially.

Hydroponics

Artificial Growing

Artificial growing provides the advantage of having total control over the nutrients the plant does and does not get. This also provides an opportunity to add other things into a chemical solution (e.g. hormones to regulate growth, chemicals to control pathogens). It also presents the challenge of trying to balance what is supplied and how it is supplied.

Artificial growing can be more complicated, but if managed really well, it provides opportunities that do not exist when you grow plants in soil.

Plants obtain nutrients two ways:

1. Through the roots – mostly mineral salts dissolved in water are absorbed through roots.

2. Through foliage – mostly carbon dioxide and oxygen gasses are absorbed through foliage.

Note: Oxygen and carbon dioxide can be absorbed through roots to some extent. Water and other nutrients can be absorbed through foliage too.

Other than Carbon (C), Oxygen (O), and Hydrogen (H), plants need a range of macro and micronutrients in order to grow well. The six macronutrients (needed by plants in larger amounts) are: Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca), and Sulphur (S).

Micronutrients (or trace elements) are taken up in much smaller (even minute) amounts and include Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B), Molybdenum (Mo) and Chlorine (Cl).

Most soils have ample quantities of calcium and magnesium and therefore fertilisers used in general horticulture are almost completely made up of nitrogen, phosphorus and potassium (NPK). In hydroponics though, it becomes necessary to add large amounts of magnesium and calcium.

Tissue Culture

Tissue culture is a method of propagating and growing plants from small pieces of plant tissue, sometimes so small that magnification is necessary when handling them. The tissue used does not contain plant parts like roots, stems and leaves but rather just cells from roots, stems or leaves. Or it may contain undifferentiated meristematic tissue (like stem cells from a human). Plants cultivated this way will require both a mixture of nutrients to feed them and other chemical additives: vitamins, carbon, sometimes hormones (growth regulators to encourage cell differentiation), sometimes specific reagents to restrict growth so as to stimulate them to grow all the different types of cells needed to become a complete plant (i.e. roots, stems and leaves). This makes the culture medium and medium formula used the most crucial aspects of successful tissue culture; the medium formulae vary depending on the purpose of the tissue culture.

Because a plant grown this way is incomplete, and very tiny, it is particularly vulnerable to diseases; hence it needs to be grown under laboratory conditions until it is large enough to resist disease, absorb nutrients through developing roots and continue to grow without a high level of assistance.

Tissue Culture

Hydroponics

Hydroponics involves growing plants without soil; but it is different to tissue culture in that the plants have fully differentiated tissues (i.e. stems, roots and leaves) from the start; and the plants are larger and more able to grow without the level of protection and human intervention provided for tissue culture in a laboratory.

Both tissue culture and hydroponics share one thing in common – the grower is taking control over supplying nutrients to the plant. In doing so, the grower has the potential to manage the plant growth more effectively that what is possible when growing is soil.

Nevertheless, every plant species is different and has different nutritional requirements. Therefore, the optimum nutrition required by each type of plant will be different. The nutrients made available by soil, or by feeding plants can have a big impact on the status of a plant in many different respects:

- Vigour
- Tolerance to different types of adversity (e.g. environmental extremes, disease)
- Type of growth (e.g. fruit, flower, foliage, roots)
- The quantities of different chemicals found in the plant tissues

The nutrients which a plant absorbs and incorporates into its tissues will affect its chemical composition. Food crops, for example, can become more or less nutritious. Plants may develop more or less of one type of tissue (e.g. leaves, flowers, fruit).

How Plants Uptake Nutrients

To gain a better understanding on how to formulate and supply nutrients to plants in the rates that are needed for good, healthy plant growth in hydroponics – you need to know, in a general sense, how plants uptake and use nutrients.

Nutrients available to the plant vary depending on the chemical and physical nature of the environment, the species being grown and its stage of growth. Plants obtain a substantial portion of their oxygen from the atmosphere. The remainder of nutrients, including hydrogen, required for plant growth absorbed from soluble elements in water.

Light intensity, temperature and water supply determine how effective plants are at using available nutrients. Nutrients and water absorbed are translocated through the plant dependent on the relationship with the membranes and the solution, and the concentration of nutrient ions around a plants root zone.

Plant nutrients can be supplied, broadly speaking, in three different forms:

1) Water-soluble simple chemical compounds: nutrients in these compounds are readily available to plants (i.e. the plant can absorb them quickly and easily).

2) Less soluble simple chemical compounds: the nutrients in these compounds can be used by plants without needing to undergo any chemical change, but because they don't dissolve so easily in water, they aren't as readily useable as the more soluble compounds. The diminished solubility may be because of the nature of the compound (e.g. superphosphate) or may be due to something else (e.g. slow-release fertilisers, such as Osmocote, which are made by incorporating the simple chemicals inside a semipermeable bubble where nutrients move slowly out of the bubble). This second group of nutrients when placed in soil will last longer than the first group of water-soluble nutrients.

3) Complex chemical compounds: these require chemical changes to occur before the nutrients can be absorbed by plants. They include organic manures and fertilisers which need to be broken down by soil microorganisms into a form which the plant can use. They also include other complex fertilisers which need to be affected by natural acids in the soil, or heat from the sun, to become simple compounds which the plant roots can use. Complex chemicals release their nutrients gradually over a long period of time, depending on the range of chemical changes needed to take place before the plant can use them. Plants grown in soil derive their nutrients from all three types of compounds. The availability of these compounds varies according to not only the group they come from but also according to factors such as heat, water, soil acids and microorganisms present. As such, it is impossible to control the availability of nutrients in soil to any great degree.

Prior to their absorption into root cells, nutrients reach the surface of roots by three mechanisms: mass flow, diffusion, and root interception.

Mass flow: this is the most important of these mechanisms quantitywise, and is the movement of plant nutrients in flowing soil solution.

Diffusion: this is movement by normal dispersion of the nutrient from a higher concentration (such as near its dissolving mineral source) through soil water to areas of lower concentration of that nutrient. It is different to osmosis which is where solvent molecules will move through a *semipermeable membrane* from a region of low solute concentration to a region of high solute concentration.

Root interception: this is the extension (growth) of plant roots into new soil areas where there are untapped supplies of nutrients in the soil solution.

All three processes are in constant operation during growth. The importance of each mechanism in supplying nutrients to the root surface for absorption by the root varies with the chemical properties of each nutrient. Nevertheless, mass flow, because of the large amounts of water flowing to, and absorbed by, roots as water is transpired from the plant is the dominant mechanism and supplies about 80% of most nutrients to root surfaces.

The mechanisms of absorption into the root cells are not well understood. The cell walls are porous, and the soil solution can move through some or all of the cell walls, causing intimate contact of the soil solution with the outer membranes of the cells. For a nutrient to cross a cell membrane into the cell, it is believed that each nutrient ion must be attached to some carrier. The carriernutrient complex can pass through the membrane into the cell. The necessary carriers are different for many of the nutrients. This means of nutrient absorption allows the root to have some selectivity in the kinds of elements absorbed. Some elements can be partially but not entirely excluded from absorption; others can be preferentially absorbed even against a concentration gradient (can be absorbed from a low concentration soil solution and transferred to a higher concentration in the plant cell).

A poorly understood mechanism of electrical balance seems to be involved in ion absorption and accumulation also. As nutrient cations are absorbed, H^+ ions are excreted into the soil solution or more organic acid anions are produced inside the cell to balance the absorbed cations. Likewise, as nutrient anions are absorbed by the plant, more compensating cations are absorbed and/or $HC0_3^-$ ions are excreted into the soil solution in order to maintain them or the electron balance in the cell. Perhaps the H^+ ions and $HC0_3^-$ ions are excreted into the soil solution first in order to aid solubility of soil nutrients. The exact processes involved still remain unclear.

Plants also absorb nutrients through small openings in leaves called the stomata. Carbon enters almost entirely through the stomata as carbon dioxide (CO_2), and the oxygen is released during photosynthesis in a gaseous form. Hydrogen, as a part of water molecules, is also absorbed through stomata but this intake is usually small compared to the amount which enters through the roots.

How Plants Absorb and Use Nutrients in Hydroponics

Grown in soil, plants source the nutrients they need from decomposed organic matter, from added fertiliser, or both. Decomposed organic matter is broken down by microorganisms into its elemental form and is comprised of a range of minerals needed in order for plants to grow. The elements made available through the activity of microorganisms and other soil life are absorbed by the plant's roots (as described earlier), but this absorption cannot occur without the presence of water since available nutrients need to be dissolved in water in order for a plant to take them up. The same applies to added fertiliser. It is added to improve the activity of soil microorganisms which break it down so that it can be used by plants. However, fertiliser needs to be added to soils in controlled amounts because too much fertiliser adversely affects the activity of (or may cause the death of) microorganisms.

In hydroponics, you circumvent the activity of soil microorganisms because firstly you are growing the plants in a sterile, soilless medium, and secondly because the hydroponic nutrients you supply are already dissolved in water and are much more directly absorbed by plant roots. In hydroponics nutrients can be added in far higher concentrations than soil fertiliser because there are no microorganisms that need to be protected.

For the reasons described above, you cannot use fertiliser in a hydroponic system and you should never use a hydroponic solution on garden soil.

HYDROPONICS TECHNIQUES

a) Solution Culture Systems

Nutrient film technique (NFT)

An NFT system operates on the principal of a thin 'film' of nutrient, only a few millimetres deep, which flows along the base of a channel. Roots are not completely submerged in the channel, but remain moist through capillary action which wicks the nutrient film flow upwards and into the root mat. For NFT systems to remain effective and provide a healthy root environment, the depth of the nutrient solution should not increase over time and flood the channel and root system. Correct slope and flow rates ensure the nutrient film is maintained at a suitable level.

Plant roots require oxygen. If a plant's root system does not receive ample oxygen or dissolved oxygen in the water, the plant will die. In an NFT system the plant's roots are exposed to oxygen in the channel and through dissolved oxygen in the nutrient solution flowing through its roots.

The design of the NFT is important in supplying both nutrients and oxygen to the plants. As mentioned, plants not receiving enough oxygen through the root system will be hindered in growth or potentially die. Generally, square channel drains which are fully enclosed are used in a hydroponics system. The main reason for this is to allow the plants root system to develop in adequate space, which exposes the roots to flowing oxygenated nutrient-rich water.

Usually, narrow channels are used for fast growing crops such as lettuce and leafy greens whereas wider channels are used for plants such as tomatoes or strawberries which take longer to grow. The larger channel is required for these plants not only because they take longer to develop but they also have a considerably larger root system. Channel sizes usually range in size from 100mm or 4-inch-wide for fast growing crops, through to 200mm or 8-inch-wide for longer term crops.

The slope of the channel is also a key requirement in supplying nutrients and oxygen to the plants. A slope of 1:40 is usually required to keep an adequate flow rate around the plant's root zone. This helps with keeping the water oxygenated and prevents dead spots in the channels, hence minimising the risk of disease.

Nutrients for NFT should be formulated specifically for this system, the crops to be grown, and the time of year/season. The choices for suppling nutrients to a NFT system come down to purchasing a manufactured mix, or making the mixes yourself.

Using a manufactured mix one can tailor the formulation in relation to the hardness or softness of the water, the make-up of the mix, and number of trace elements. It should also indicate whether the mixture is suitable for hard or soft water, in which case there will be a slight variation in pH. The main advantages of using a manufactured mix are the ease of mixing (with the right volume of water) and the purchase price.

Making your own nutrient solution involves carefully measuring the amount of nutrients for your system.

This can work out less cost effective than using a manufactured mix as the individual ingredients have to be purchased, measured and added to water. Generally, a high-quality mix is recommended because it will usually be more soluble than a cheaper alternative. There are many nutrient recipes to follow which give a break-down of nutrients by weight per designated volume of water. Again mixes can be used in both hard and soft water however the pH can be adjusted by using phosphoric acid.

Raft, float and pond systems

Other popular solution culture systems include raft, float, pond or raceway systems, or deep flow culture (DFT). These systems operate on a static or gentle flow of a large volume of nutrient solution contained in ponds or raceways. The depth of the nutrient solution may be anywhere from 15cm to 60cm. Plants are supported by floats constructed from closed cell polystyrene which provide a frictionless conveyor on the surface of the nutrient solution. Larger plants may be supported by other methods.

The nutrient pool is often maintained with a gentle flow rate which circulates through the plant roots, providing fresh supplies of dissolved oxygen and nutrients to the roots. Oxygenation is assisted with the use of air bubblers, cascade or spray methods. Temperature, nutrients and pH are adjusted as required.

Float systems are commonly used for the large scale production of small plants such as lettuce, herbs and Asian greens, while DFT is used commercially for some longer term crops such as tomatoes.

Crops such as strawberries which are prone to disease under saturated conditions are not suited to float systems.

The advantages of float or DFT systems are that no substrate is required to support the plants and the large volume of nutrient solution has a high buffering capacity, thus slowing changes in temperature, pH, EC and nutrient levels over time. The disadvantage is that being a recirculating system, root disease outbreaks can spread through an entire crop rapidly and treatments are often put in place to lower this risk.

Aeroponics

Aeroponics, while not used on a large scale commercially, is another solution culture system which requires minimal use of substrates apart from in the propagation phase. Aeroponic systems maintain the root systems hanging inside a lightproof chamber where nutrient solution is sprayed, either continually or intermittently, over the roots. This method ensures a high level of oxygenation for root tissue functioning and thus can achieve good growth rates. The disadvantages of aeroponics are the requirement for large capacity pumps and tendency of the spray nozzles to block frequently with nutrient deposits and root material. Modifications on the aeroponic technique include ‘fogponics’ where the nutrient solution is applied as very small droplets in the air of the root chamber.

b) Substrate Culture Systems

Rockwool

Rockwool is a media used for growing plants in a hydroponics system, it can also be incorporated into an NFT system and it is probably one of the most extensively used mediums. Rockwool is made up from volcanic rock, coke and limestone melted at very high temperatures and fine threads are pressed into loosely woven sheets. Initially the rockwool is slightly alkaline having a pH of between 7 and 8.5, however this pH is easily lowered to suit plants being grown hydroponically.

Rockwool is purchased dry, so treatment is required to ensure that it is ready to be used in a system. Before introducing plants, the rockwool needs to be soaked or irrigated with water to thoroughly wet the substrate. Nutrient solutions can be introduced after planting. Water and nutrient solution can be applied via drippers or emitters to the rockwool housing the plant or directly to the base of the plant.

There are many advantages of using rockwool in hydroponics. It holds moisture and nutrients really well, and the nutrients are fed to each individual plant which ensures a uniform distribution of fertiliser. It helps keep the roots oxygenated and thus helps the plant to develop a healthy root system. Also, this form of medium is purchased sterile and so it is disease-free. Rockwool can be used more than once, and growers have the option of sterilizing it using steam. It comes in various sizes or can be cut to size to suit the hydroponic system. Generally, there is little crop setback after initial transplanting, and it is generally the least expensive to set up.

These days, hydroponic rockwool products are fully buffered and of a suitable pH after manufacturing so they no longer require the ‘buffering’ with acids or nutrient solutions before planting to adjust pH. One of the main disadvantages with rockwool in many countries is disposal after its usable life span. While rockwool can be steam sterilised and used for several crops were this is possible, it eventually must be replaced and disposal is often in landfill. Some growers shred rockwool and incorporate it into soil as a conditioner however the majority of used rockwool worldwide is not recycled. There is also a risk of harmful salts building up in the medium. Rockwool may not be available locally in all countries.

Gravel bed

A gravel bed is probably one of the first mediums used in modern hydroponics. It is a relatively inexpensive material to use, although initial set up and structural costs can be expensive. Some preparation is required when using gravel in a grow bed. Time must be spent washing and removing any impurities from the medium since small particles have the potential to cause blockages. Many different mediums can be used in a gravel beds. Choice and availability will vary across the world with different materials sourced locally. Some examples of different materials are clay balls, expanded clay (e.g. Haydite and Herculite) which is lightweight but expensive, drainage gravel, perlite and scoria. The size of the aggregate must be large enough to not cause blockages and to not break down in the beds. It should also be able to retain moisture and allow for good aeration around the plant’s root system.

Care must be taken if using calciferous material, as this may modify the pH of the solution. The calcium carbonate present in limestone and coral gravels can react with some of the fertilisers in the solution causing a shift in pH. Good results have been achieved by using Haydite or Herculite, which are both lightweight mediums. Being of a porous nature, there is a potential for a build-up of salts in the beads over a period of time. These salts may be difficult to remove from the medium. Another problem is that this type of medium is fairly brittle and pieces may break off causing blockages in the system.

When using gravel beds to grow plants hydroponically, consideration must be given to the irrigation system used. Unlike an irrigation system used in an NFT design where solution is available to the plant all of the time, water must drain from the root profile to help keep the root zone oxygenated. A flood and drain system is popular with growing plants in a gravel bed. This system allows the water to reach a certain level in the bed, usually within 75mm of the top of the gravel, keeping the rootzone moist and draining back into the reservoir. Another method is to have the bed irrigated by pumping water in on a timed schedule. When using either of these systems the key to proper hydration is flooding the beds quickly and draining them rapidly.

Other substrate systems

Along with drip irrigated rockwool systems, a wide range of solid substrates are used in hydroponic systems. These include peat, coconut fibre (coir), perlite, vermiculite, scoria, pumice, sawdust, rice hull, bark, sand, LECA (light expanded clay aggregate) and an increasing range of organic materials. While some of these substrates such as perlite and vermiculite are chemically inert and do not influence the composition of the nutrient solution, others, particularly organic substrates, may interact with nutrition and require different formulations to obtain the optimal growth rates.

Coconut fibre (coir)

Coconut fibre or coir is a natural and renewable hydroponic substrate which has become increasingly popular over the last two decades, often as a replacement for rockwool because of the problems with disposal. Coconut fibre is a growing substrate made from coconut mesocarp pith and may also be called palm peat, coco peat, cocos, kokos, but more commonly, coir.

Coconut fibre developed for the hydroponic industry is processed to retain the correct ratio of coarse fibres and fine particles which provide specific air and water holding capacities for various crop uses. Coir is formed in compressed slabs which expand with water and are contained in a plastic wrapped sleeve in much the same way that rockwool is supplied. As a loose substrate it is used in Dutch bucket systems, grow beds, bags, containers and pots for crop production. High quality hydroponic coconut fibre has the advantage of containing low levels of salts, having been fully rinsed during processing or before use by the grower. Lower quality coir may contain high levels of natural sodium and/or potassium, particularly if the coco husks were retted in seawater during processing. The pH of most coconut fibre is usually slightly acidic with a pH in the range 5.8 – 6.5 which is ideal for hydroponic production.

Coconut fibre requires different nutrient levels and formulations in the early stages of growth than other inert substrates such as rockwool or solution culture systems such as NFT. This includes a higher nitrogen level to counter the nitrogen drawdown which occurs initially in coconut fibre as well as lower levels of potassium (coconut fibre contains naturally occurring potassium which is available for plant uptake in the few weeks of use as a hydroponic substrate). Higher calcium and iron nutrient levels are also supplied in the early growth phase with coconut fibre substrates. Commercial bottled nutrient products often contain a 'coco formulation' in their range to allow for these requirements. Coconut fibre can also be preconditioned or 'buffered' with a solution of calcium nitrate after the expansion phase but before planting out a crop to assist with limiting the nitrogen drawdown issues.

Coconut fibre can be re-used for a number of successive crops, steam sterilised, and being a natural organic product it is easy to dispose off. Used coconut fibre can be recycled into composting systems, used as a soil conditioner, or used as outdoor mulch with minimal environmental effects.

Differences between nutrients for recirculating and non-recirculating systems

Some hydroponic techniques such as NFT, float or raft systems and some substrate systems recirculate the nutrient solution whereas others are termed 'drain to waste' or 'run to waste' where the nutrient solution drains away and is not reused for further application after it has been irrigated onto the plants. The difference between growing in a drain to waste system compared to a recirculating system such as NFT is largely due to EC. Nutrients do not become imbalanced in drain to waste media systems to the extent they can in NFT since the nutrients are continually drained away. Generally, solutions used in drain to waste systems are run at a lower EC than if the same solution was running in a recirculating solution culture system, but they may also have lower phosphate content.

Make or buy the nutrients?

For many who are new to hydroponics or tissue culture there is a desire to mix their own nutrients.

Most commercial-sized operations, and many small-scale growers, mix their own hydroponic nutrients from the individual fertiliser salts. This not only saves considerable expense where fertilisers can be purchased in bulk, but it also allows the flexibility to adjust nutrient solutions in accordance with minerals present in the local water supply, for the climate, and for the stage of crop growth. For different nutrient formulations, or recipes, the actual process of weighing out the individual fertiliser salts, mixing them into water, and diluting for crop use is not complicated but easy to understand. What can be more challenging however is obtaining and potentially modifying a suitable nutrient formulation or recipe for the crop being grown. Many sample formulations are published in books, available on the internet, or can be obtained via hydroponic consultants and other growers. However, sometimes taking a formulation from one grower or reference source and using it in another situation may not be ideal since nutrients often need to be customised for each particular growing operation. Nutrient formulation software includes sample formulations which allow growers to use automatic adjustments for a crop's stage of growth, the season and minerals in the water supply. These are a good way of obtaining a suitable nutrient formulation for a hydroponic operation.

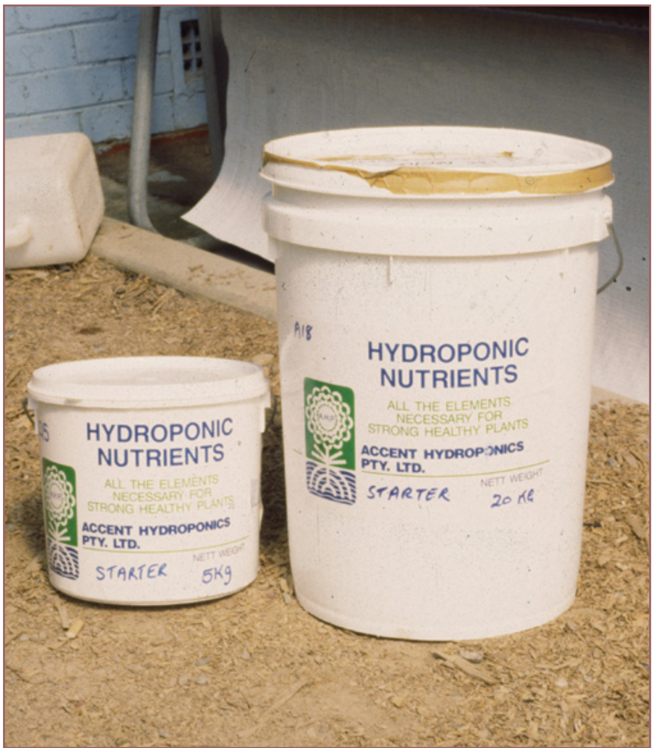
For home hydroponic systems where only small volumes of nutrient stock solutions are required, buying a bottled or solid premix packaged product is fine because it avoids having to buy the individual fertilisers in bulk and store them long term.

Depending on the season and the stage of plant growth, nutrients may only last for 2-3 weeks in a hydroponic reservoir. This may be even shorter during the summer months. Regular testing of nutrients in the reservoir can become an unwanted expense for small growers or home gardeners. So, the only safeguard against a nutrient deficiency or disorder is to change the solution periodically.

Hydroponics

CHAPTER 2 PRE-PACKAGED NUTRIENTS

Pre-mixed chemicals may be purchased as either liquids or solids, and in either twin packs or single packs. A single pack chemical is ready to use as it is. Twin pack chemicals have components separated because once mixed, they may interact and start a chain of changes which could culminate in chemicals you may not want to have in your mix. They need mixing and using straight away before the process of changes gets significantly underway.



Hydroponic nutrients

Using Solid Nutrients

Powdered nutrients may have a few advantages over liquids. For example, the 'base' product weighs less making it easier to transport and store. Also, some chemical additives may keep better and longer in a powdered form than mixed with other chemicals as a liquid. However, powdered nutrients may be at risk of uneven mixing more than pre-mixed liquids.

Consider: a pre-mixed liquid is 10% (by volume) solid additives suspended in 90% water compared with that same mix of chemicals in a powdered form. If you were to add 1 litre of liquid to a large tank, the chances of diverging from the ideal concentration would be less than if you were adding a quantity of powder that is only 10% of the volume. Powder added directly into a tank might not all dissolve either.

Definitions:

Percentage weight/volume (% w/v) = the weight in grams of a solute per 100 millilitres (ml) of a solution. For example, 2 grams of a solute in 100ml of water is expressed as 2% w/v.

Percentage weight/weight (% w/w) = the weight rather than the volume used. For example, if in a total mass of a 100 grams solution 40 grams of a solute was used - it would be expressed as 40% w/w.

Solutions and Precipitates

Precipitates are formed when nutrients are combined in high concentrations.

For example, when calcium (which is positively charged in the solution) reacts with sulphate ions (which are negatively charged), insoluble calcium sulphate is formed. This reaction also happens when calcium and phosphate are combined in high concentrations, with the precipitate being insoluble calcium phosphate. Besides calcium sulphate and calcium phosphate, another nutrient which is precipitated out of a solution is iron phosphate.

Usually, it is not a problem when nutrients are mixed together in smaller doses or normal feed strengths. To overcome this problem for solutions which need to be mixed at higher concentrations, they are split into part A and part B. Part A solutions contain nutrients such as calcium nitrate and iron chelate. Part B solutions have all the other nutrients. These two mixes are then added separately to the solution into the water flow making the two ingredients fully soluble. Commercially the two solutions would be injected into the water flow.

Precipitation also occurs when there is a shift in pH which renders some nutrients insoluble and unavailable to the plant. If using powder, it is often recommended that you pre-mix it to create a concentrated liquid solution, and then add this solution to the tank.

Why Twin-Pack Chemicals?

Twin packs are a convenient way of keeping calcium in phosphates separate from calcium in sulphates. Twin packs use a Nutrient A and Nutrient B component, ensuring that certain incompatible salts are not mixed together and hence precipitate out of the solution. The main culprits for being incompatible are those already mentioned i.e. calcium and phosphate, calcium and sulphate and phosphate and iron.

Why Single-Pack Liquid Solutions?

Liquid fertilisers are usually used for smaller hydroponic systems and are seldom used commercially. One of the main advantages of using a liquid fertiliser is that the ingredients are complete and in one part ready for use. They only need to be added to the water.

When the complete hydroponic solution is pre-mixed as a concentrate (i.e. a single pack), there is a high chance of chemicals precipitating out of solution. For this reason, the bottle needs to be shaken vigorously until all solids are fully dissolved before use.

Organic Solutions

It is important to understand how liquid organic fertilisers work if they are ever used in hydroponics. Organic chemicals can contain many of the chemicals needed to feed plants; but they are commonly present as very large, complex molecules. When an organic fertiliser is added to soil, these complex molecules may be broken down by microorganisms to create smaller molecules which are then absorbed by the plants. In a hydroponic system though, soil is absent. This can mean an absence of disease organisms (a good thing) but also an absence of beneficial organisms (which may prevent action on the organic molecules so they are less usable by plants).

Organic hydroponics can be successful, but only when this limitation is recognised and accommodated in some way. Because most organic fertilisers are carbon based, the measurement of EC (Electrical Conductivity – discussed in more detail later in this text) of a solution will be higher than the reading given. Unlike synthetic fertilisers such as calcium nitrate, which are completely soluble making the nutrients available to the plant immediately, replacing these nutrients organically can be more challenging.

With the high content of carbon associated with organic fertilisers, this carbon feeds both beneficial and harmful microbes in the solution and root zone. It is recommended that plants be grown in a substrate which has a large surface area which can house the large population of microbes required to break down (mineralise) the organic fertilisers. A free-draining media is required allowing for good aeration around the root zone and a sufficient supply of oxygen to the beneficial microbes.

Because the system relies on beneficial microbes mineralising the nutrients, a different irrigation frequency and duration needs to be used as there is a fine balance supplying enough nutrient and oxygen to both the roots and the microbes. Due to the dependence of higher oxygen levels required to sustain the population of microbes, over watering can be very harmful.

EC readings may not give a true indication of the amount of solution in the system due to the carbon associated with organic fertilisers. Since acid is introduced to modify the pH in a system using soluble fertilisers, modifying the pH in an organic system can be more difficult.

While there is a range of nutrients available on the market for plants to be grown organically, the problem lies in the concentration of these solutions. Solutions such as fish emulsion, seaweed based fertilisers and worm casts (vermicasts) are used to fertilise plants organically.

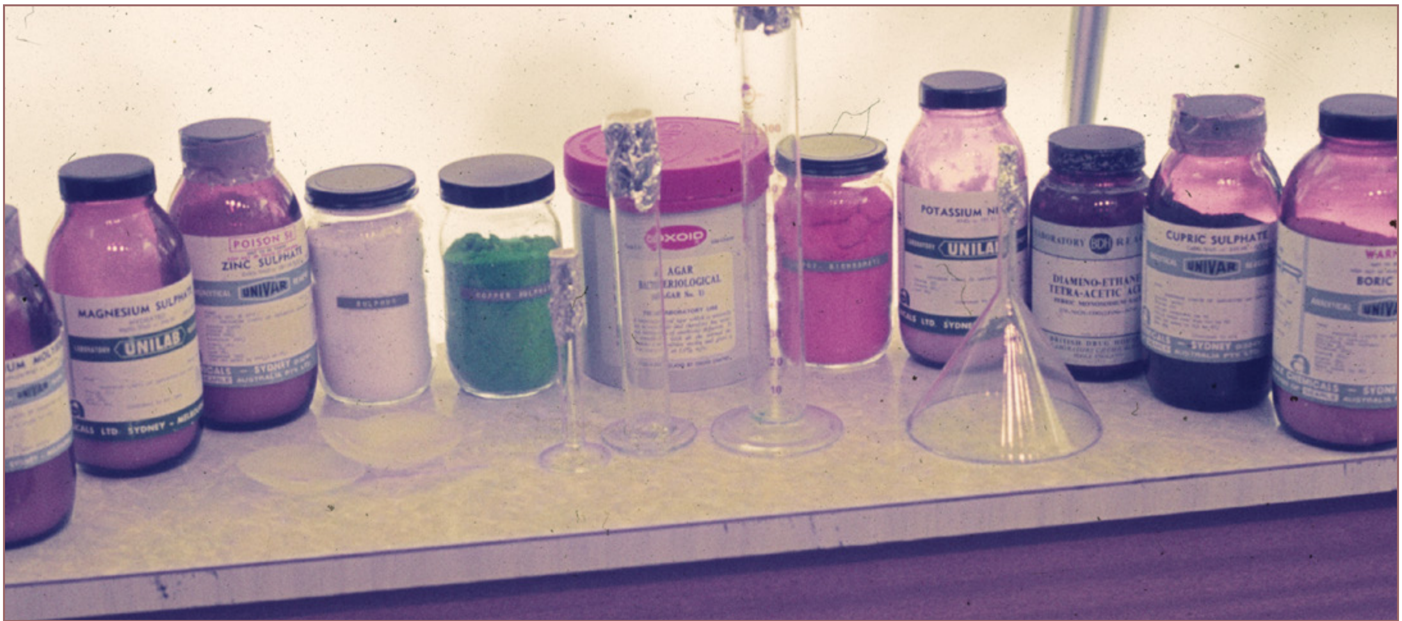
So, while organic hydroponic plant culture is possible, the use of 'organic hydroponic nutrient solutions' is a much more complex and larger topic than what can be covered here. Before you can fully start to explore and understand organic nutrient management; it is wise to first get a solid understanding of managing hydroponic nutrients in a non-organic situation.

Organic hydroponic solutions and organic hydroponic substrate and NFT systems are becoming a larger part of the hydroponic industry, particularly in countries where organic hydroponics can be fully organically certified (e.g. United States).

CHAPTER 3 CHEMICAL COMPONENTS

For hydroponics, greenhouse grade fertilisers are commonly used. These are not as pure as laboratory grade but less expensive and perfectly adequate for growing hydroponic crops.

For tissue culture, laboratory grade chemicals are more commonly used since much smaller quantities of chemical are needed, and plants are more susceptible to problems.



Important Chemicals for Plant Growth

Types of Chemicals

The chemicals used will exist as compounds, made up of two or more different elements (types of atoms). This means, in order to supply a nutrient (type of atom) needed by the plant you will also be supplying other types of atoms (discussed in more detail later). Sometimes those attached atoms are harmless by-products, sometimes they can also be used by the plant, but at other times they are undesirable and if residue builds too much they may damage the plant.

Supplying nutrients to plants in a hydroponic system involves dissolving fertiliser salts in water to supply the appropriate nutrients to growing plants. These different fertiliser salts have various levels of solubility. Fertiliser solubility is the measure of fertiliser remaining in the solution after it has been diluted with water. It is essential to use fertilisers with high solubility as these will remain suspended in the solution and available for the plants to use. Commercial growers most commonly use powdered fertiliser whereas the hobbyist is more likely to use liquid fertilisers.

Essential nutrients for all hydroponic systems are: Nitrogen (N), Potassium (K), Phosphorus (P), Calcium (Ca), Magnesium (Mg),Sulphur (S), Iron-(Fe), Manganese (Mn), Copper(Cu), Boron(B), Chlorine (Cl), Molybdenum (Mo) and Zinc (Zn).

What Are Ions?

Ions are molecules in the solution which are electrically charged particles. They are either positively charged (cations) or are negatively charged (anions). These are measured in the solution to test for the electrical conductivity (EC) by using an EC meter. Electroconductivity is measured in 'Siemens' and is represented by s/cm. Measuring electroconductivity is a way of monitoring the amount of nutrient in the solution. For example, if salt (sodium chloride NaCl) is added to water it splits, becoming two electrically charged particles: Na^+ and Cl^-.

However, some organic compounds do not register on an EC meter (see below). It is only inorganic ingredients in a hydroponic solution which can be measured. The number of ions suspended in a solution can vary. Water loss through transpiration will cause the water level to drop concentrating the amount of nutrient in the solution. A low EC reading will result in a yield, with a higher EC (see below) reading producing a healthier higher yielding plant. An EC reading below 1.0 mS/cm around the plants roots is considered a low reading.

What Are Mineral Salts?

Mineral salts used as plant fertilisers are not like table salt (sodium chloride) and shouldn't be confused with it – commercial fertilisers have negligible amounts of sodium chloride in them. Plants need dissolved nutrient salts to survive; it is getting the right salts and in the right concentrations that is important to plant growth and health.

Salts are the result of a chemical reaction between an acid and a base; many nutrients in hydroponic nutrient solutions are added as mineral salts. This means the minerals needed, like potassium (K), are added as part of a compound, like potassium nitrate (KNO_3).

Nutrient elements we see in fertilisers are produced in fertiliser plants and are derived from natural sources, for example:

- Ammonia is produced from atmospheric nitrogen and hydrogen
- Ammonium nitrate is manufactured from ammonia and nitric acid (nitric acid is manufactured from ammonia and is not used in hydroponics)
- Ammonium phosphates are produced from ammonia and phosphoric acid
- Potassium chloride is a mined ore product which is then crushed and purified
- Sulphuric acid is derived from oil and natural gas
- Phosphoric acid is manufactured from phosphate rock (e.g. calcium phosphate)
- Triple phosphate (super phosphate) is made from phosphoric acid and phosphate rock (and is not used in hydroponics)

The presence of mineral salts means the nutrient solution can carry a current i.e. it has electrical conductivity.

Electrical Conductivity

Electrical conductivity (EC) is a measure of the salinity of the soil, or the nutrient solution in hydroponics. That is, it is used to determine how many salts are present in the soil or nutrient solution. As a comparison, purified or distilled water doesn't conduct electricity and will always have an EC reading of zero. The greater the amount of dissolved mineral ions (fertiliser) in the water, the higher the electrical conductivity will be. Therefore, high EC readings mean high levels of nutrients and low EC readings are a determination of low concentrations of fertiliser salts in the water.

EC readings are important since they reflect the extent to which the salts present in the solution affect the way that plants will grow; measuring EC means that you can ascertain if the plants fertiliser needs are being met. It can also determine if there is an over-supply of nutrients in the water. The most common cations (positively charged ions) are calcium, magnesium, sodium and potassium, and the most common anions in hydroponics (negatively charged ions) are nitrates, sulphates and phosphates. Fertilisers and manures can contribute others, such as ammonium.

As salts are dissociated into ions in solution they carry a positive or negative charge (e.g . KNO_2 dissociates to K^+ + NO_3^-) which can transmit electricity. Pure water will not transmit electricity, but as soon as salts are added, the ability of the solution to conduct electricity increases. This conductance increases with increasing solution strength. CF (conductivity factor) and EC (electrical conductivity) are a measure of this characteristic of nutrient salt solutions. While EC seems to be a very convenient measure, there are problems associated with relying only on EC to control hydroponic nutrient formulae. For example:

The EC will be roughly the same regardless of the elemental content of the solution. A nutrient solution with an EC of 2.0 cannot be distinguished from a solution of sodium chloride with an EC of 2.0.

Different nutrient salts show different capacities to conduct electricity when in solution so that depending on the nutrient rations and the individual salts used, the EC may give a very different indication of the true ionic strength of the solution. A solution of potassium nitrate at EC 2.0 will be approximately half the strength (in ppm) of a solution of magnesium sulphate at EC 2.0. This is because potassium conducts almost double the amount of electricity at the same ionic strength as magnesium sulphate (shown in the table below).

Even if the nutrient content of the formula was known accurately at the start, once the solution has been recirculating through a growing crop for a few weeks the elemental content changes – the EC may well stay the same.

Table: Conductivity of some common hydroponic nutrients at 2000 ppm

SALT	mg/l	CF	EC
Calcium nitrate	2000	20	2
Potassium nitrate	2000	25	2.5
Magnesium sulphate	2000	12	1.2

The EC of a nutrient formulation is a combination of the EC contributed by all the dissociated nutrient salts from the A and B stock solutions as well as impurities from the water supply and is not really any indication of the quality of the formula, just as estimate of the strength. In hydroponics, the way to determine the nutrient makeup of a formulation is to have a complete mineral analysis done, use a range of specific ion meters, or to calculate the nutrients in advance and use these in drain to waste systems. Outside of hydroponics, or in organic hydroponics, EC may not even be a measure of strength of a formulation as a range of compounds such as organic nutrient complexes and chelates do not conduct electricity.

Note: When testing the EC of a solution, there is no differentiation between the positive and negative ions, it only measures the total number of ions; EC does not measure individual solutes (dissolved compounds) within the nutrient solution. It cannot identify proportions of, say, potassium to magnesium in the solution. When a nutrient is used by the plant, some of its original compound is left in the solution. This increases the EC of the solution, which makes EC a useful diagnostic tool because it can be used to help estimate how much of the nutrients in a solution have been used over time.

Managing EC

EC can be managed, at appropriate times, to generate vegetative growth or flowering and fruiting. It can also be used to reduce stress in plants due to environmental conditions. Plants can stress or alter growth patterns in changing environmental conditions so EC management is helpful in reducing that. When conditions are cool and light levels are low, plants tend to move towards the light causing elongation of the internodal spaces (long sappy weak growth of the stems). By raising EC levels, growth can be restricted which reduces this problem. Conversely, in hot and dry conditions EC levels may be lowered to compensate and reduce plant stress caused by these types of conditions.

TDSEC and TDS (total dissolved salts in a solution) are both terms used in hydroponics. They both refer to measures of electrical conductivity.

- EC readings are displayed in millimhos or mmhos/cm; the units of conductivity per centimetre
- TDS readings are displayed in ppm

(part per million) – these meters use a conversion factor that then displays an EC reading as a TDS reading. The conversion rate is usually 700:1 so a TDS reading of 700ppm will have an EC reading of 1.

Conductivity Meters

Conductivity or EC meters are one of the least expensive items of soil/solution testing equipment. Conductivity meters are devices used to measure the salinity of water. An electrical device generates an electrical signal which travels between two electrodes. The ability of water to conduct electricity between these two electrodes is an indication of the dissolved salt - if the electric current flows more, then there will be more dissolved salts. Low electroconductivity (EC) readings indicate low concentrations of nutrients salts. Very high EC readings can indicate toxic levels of nutrients.

The Role of pH in Hydroponics

A pH reading is a measurement of the hydrogen ion concentration in a particular medium, such as water, soil, gravel, etc. More simply it refers to the acidity or alkalinity of that medium. The ph is measured on a logarithmic scale ranging from 0 to 14 with 7 being considered neutral, above 7 being considered alkaline and below 7 as acid.

The pH of a medium or a nutrient solution is important to plant growth. Each particular plant has a preferred pH range in which it grows. If a plant is subjected to a pH outside its preferred range at the least its growth will be retarded, or it may even die. Very low pH (less than pH = 4.5) and very high pH conditions (above pH = 9) can directly damage plant roots.

Most commercially grown hydroponic species prefer a slightly acidic solution in the pH range 5.8 to 6.5. However, plants can survive in the pH range 5 to 7.5. As the pH rises from 6.5 to 7.5 or 8, some elements such as iron, manganese and phosphorus become less available and deficiency symptoms may begin to show, even though these nutrients are present in sufficient levels in the solution. Too high a pH will precipitate out iron in hydroponic solutions making it unavailable for plant uptake and causing chlorosis of the upper leaves. Some forms of iron chelate can withstand higher pH levels than others and this should be taken into consideration when formulating nutrient solutions using water supplies with naturally high pH and alkalinity. Growers should be aware that the availability of nutrients at different pH levels differs for soilless mediums compared to mineral or organic soils, and so diagrams shown in reference books for soils are not accurate for hydroponic crops. Optimum pH levels differ for various crops with tomatoes, for example, preferring an optimum pH of 5.8 - 6.0, while lettuce prefers 6.0 - 6.2.

As the pH of a medium changes so does the availability of nutrients. The majority of nutrients are most available at a pH range of 6 to 7.5. Somewhere in this range is generally considered to be the ideal for growing the majority of plants although there are plants that prefer higher or lower pH conditions. In some circumstances, particularly at very high or very low pH conditions, some nutrients may become 'locked' in the medium, becoming unavailable for plant growth. The nutrients may be there in the medium but the plant can't use them. At very low pH condition toxic levels of some nutrients such as manganese and aluminium may be released.

As the pH of some media is raised, more negative charges are produced on some colloid surfaces making them capable of holding more cations. This allows some media to hold larger quantities of nutrients. The majority of hydroponic media are not affected in this way as they are basically inert materials such as sand and gravel, however media that contains clays or some of those derived from volcanic materials can be affected.

What Are Solutions?

In hydroponics systems, plants take up much more water (at a higher rate) than they do nutrients. It is estimated that a system can lose between approximately 5-30% of its volume depending on number and types of plants being grown. For example, in tomatoes the water lost through transpiration at night is around 15 ml per plant per hour, but during the day transpiration increases to 130-140 ml per plant per hour in warm conditions.

In a hydroponics system all nutrients are supplied to plants as dissolved fertiliser salts. These soluble fertiliser salts which supply nutrients to the plants have different solubilities. The concentration of salt remaining in the solution after it has been dissolved is measured as its solubility. Fertilisers having high solubility should only be used in hydroponics as these nutrients need to be made available for the plant to use. A fertiliser which has a low solubility may contain impurities such as clay, sand and silt particles which may form residue in the system. A build-up of such particles can bind up nutrients and cause blockages to parts of the feeder lines. Generally, commercial fertilisers have a percentage of purity, or guaranteed analysis on the label of the bag. This is important when calculating a nutrient formula for a system.

Ionisation of Nutrients in Solution

In hydroponics, ionisation is the process whereby fertiliser salts break into their individual ions when dissolved in water. This allows rapid uptake of nutrient by plant roots.

What Does a Hydroponic Nutrient Look Like?

Hydroponic nutrients are all different. The best solution for any situation depends upon what is being grown, how and where it is being grown, and other factors such as environmental conditions. Other than oxygen, hydrogen and carbon which is supplied in the air and through the water, the following nutrient mixes are most commonly used in hydroponics:

- A NPK (Nitrogen, Phosphorus, Potassium) primary nutrient mix.
- Nitrogen as Nitrate (NO_3^-) is supplied largely as: calcium nitrate and potassium nitrate.

- Ammonium (NH_4^+), such as ammonium nitrate or ammonium phosphate fertiliser may sometimes be used in much smaller amount in hydroponics compared to nitrate and should never solely supply all the nitrogen needs in hydroponics i.e. about 30ppm or about 10% of total nitrogen with the rest (90%) being supplied as nitrate.

- Phosphate (P) is supplied by using mono-potassium phosphate (MKP: KH_2PO_4) which also supplies some potassium (K). Superphosphate is best avoided (see notes later in this text), monocalcium phosphate.

- Potassium is supplied as mainly potassium nitrate and mono-potassium phosphate. It can be supplemented with additional potassium sulphate which also adds some sulphur.

- Calcium should be supplied as calcium nitrate ($CaNO_3$).

- Magnesium sulphate ($MgSO_4$) provides magnesium and sulphur as Epsom salts.

- Magnesium and nitrogen may be supplied as magnesium nitrate.

- Plus the micronutrients may be provided in trace amounts: iron (as iron chelate), copper, zinc, manganese, boron, and molybdenum.

Note: Plants can absorb nitrogen in both the nitrate NO_3 and ammonium NH_4 form, however in soils bacteria convert much of the ammonia to nitrate before it can be absorbed by plants. In hydroponics an oversupply of ammonium in the nutrient solution is readily available for plant uptake. In this situation too much ammonium nitrogen will accelerate the uptake and utilisation of nitrogen under certain conditions which can become toxic to plant growth. The uptake of ammonium is a passive process in plants, thus the plant does not have control over how much is absorbed and toxicity levels can be easily reached causing plant damage.

We shall consider the amounts of the above nutrients commonly found in hydroponic nutrient solutions in Chapter 5.

Chemicals to be Wary of

Some chemicals should not be used. For instance, calcium, potassium and ammonium chlorides (also called muriates) may appear a good way of supplying calcium, potassium or nitrogen but they also increase chlorine levels, and excessive chlorine will damage plants.

Avoid superphosphate in hydroponic solutions because it is usually impure and can contain heavy metals.

Ammonium salts (e.g. ammonium sulphate, ammonium nitrate and mono-ammonium phosphate) can result in an imbalance between nitrate and ammonium ions and increase acidity so should be used cautiously (ammonium ions in soil are converted to usable nitrogen by soil bacteria, but as discussed previously, in hydroponics, these bacteria are usually absent).

Writing Chemical Names

The different elements have been given standard letter abbreviations. Chemical compounds or nutrient salts can be written using these abbreviations.

The elements generally considered most essential to plant growth, plus those which are commonly found in nutrient salts, are listed below with their atomic weights and abbreviations.

Table: Atomic weights of elements commonly used in hydroponic nutrient solutions

Element	Symbol	Atomic Weight (amu)
Boron	B	11
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35
Cobalt	Co	59
Copper	Cu	64
Hydrogen	H	1
Iron	Fe	56
Magnesium	Mg	24
Manganese	Mn	55
Molybdenum	Mo	96
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium	K	39
Sodium	Na	23
Sulphur	S	32
Zinc	Zn	65

Nutrient solution supplied manually here. Consider whether chemicals may settle and need mixing periodically to keep the concentration correct.

Calculating the Amount of Nutrient in a Chemical

The proportion by weight of a nutrient element in a nutrient salt can be calculated as follows:

1. Write down the chemical formula of the salt. This should be on the product label.

Example:

Ammonium sulphate $(NH_4)_2SO_4$

This simply means 2 x NH_4 plus 1 x SO_4

In total then, ammonium sulphate contains:

2 nitrogen atoms

8 hydrogen atoms

1 sulphur atom

4 oxygen atoms

2. Look up the atomic weights of each of the elements in the nutrient salt and multiply them by the number of atoms of each element present in the chemical formula for that molecule. This will give you a measurement known

as the atomic mass units, 'amu' or 'AMU' (also known as "daltons", and denoted as D). It should be noted that the terms 'atomic weight' and 'atomic mass' are often used interchangeably, but mass is the more accurate term. 1 amu = one twelfth the mass of an atom of carbon-12 (C-12). This allows us to have a measurement of mass at an atomic scale.

Example:

Nitrogen (atomic weight = 14): 2 atoms x 14 = 28 amu

Hydrogen (atomic weight = 1): 8 atoms x 1 = 8 amu

Sulphur (atomic weight = 32): 1 atom x 32 = 32 amu

Oxygen (atomic weight = 16): 4 atoms x 16 = 64 amu

3. Add up the total weights as calculated.

Example:

28 + 8 + 32 + 64 = 132

The molecular weight of ammonium sulphate is therefore 132 amu

4. Take the total calculated weight of the nutrient element (i.e. in the above example this is 28 amu for nitrogen in ammonium sulphate) and divide this by the molecular weight of the nutrient salt (in this example that would be 132 amu) giving 28/132 x 100/1 = 21.3%. This means that 21.3% of any quantity of ammonium sulphate is actually nitrogen.

Another example of Calculating the Amount of Nutrient in a Chemical:

The formula for sulphate of potash (potassium sulphate) is $K2SO_4$:

2 atoms of potassium: 2 x 39 = 78

1 atom of sulphur: 1 x 32 = 32

4 atoms of oxygen: 4 x 16 = 64

Total = 174

Percentage of potassium = 78/174 x 100/1 = 44%

Note that many of the nutrient chemicals listed in the table in the next page contain sulphur. Sulphates are commonly used because plants tolerate large amounts of sulphur. An excess of unused sulphates around a plant's roots will be less damaging than an excess of chloride or something else.

Chemicals should be stored in a dry place until you are ready to use them. Choose your fertilisers not only on the basis of the nutrients they supply but also on how easy they are to obtain and how much they cost in terms of the amount of nutrient the fertilisers supply.

The most common way of describing the content of a nutrient solution is in parts per million (ppm). Since a gram of weight is equivalent to 1 cubic centimetre of water, then 1 ppm is equivalent to 1 gram of water in 1 million cubic centimetres (cc's) of water (1,000 litres). 1,000 litres is equivalent to about 264 US gallons.
If you are using US measurements you can convert to fluid ounces by dividing grams by 28.35 and litres to gallons by multiplying litres by 0.2642.

Table: Amount of chemicals (in grams) used in making 1000 litres of nutrient solution

Chemical compound	Nutrient element supplied	Grams to give 1 ppm in 1000 L of water	Second element supplied
Ammonium sulphate	Nitrogen	4.7	
Calcium nitrate	Nitrogen	6.45	Calcium 1.36 ppm
	Calcium	4.7	Nitrogen 0.74 ppm
Potassium nitrate	Nitrogen	7.3	Potassium 2.6 ppm
	Potassium	2.8	Nitrogen 0.38 ppm
Sodium nitrate	Nitrogen	6.45	
Urea	Nitrogen	2.17	
Monopotassium phosphate	Potassium	3.53	Phosphorus 0.8 ppm
	Phosphorus	4.45	Potassium 1.26 ppm
Triple superphosphate	Phosphorus	4.78	Calcium 0.6 ppm
Calcium sulphate (gypsum)	Calcium	4.8	
Boric acid	Boron	5.64	
Copper sulphate	Copper	3.91	
Ferrous sulphate	Iron	4.96	
Manganese sulphate	Manganese	4.05	
Magnesium sulphate (Epsom salts)	Magnesium	10.25	
Molybdenum trioxide	Molybdenum	1.5	
Zinc sulphate	Zinc	4.42	

To make a solution containing, for example, 1 ppm of a particular nutrient you would need to add 1 gram of that nutrient to 1,000 litres of water. To work out how much of the particular chemical you are using to supply that nutrient you would need to add to the 1,000 litres of water, you need to know what percentage of the chemical the actual nutrient is. Based on the previous example this can be calculated as follows:

If the amount of nitrogen in ammonium sulphate is 23.1%, then simply adding 1 gram of ammonium sulphate to the 1,000 litres of water would only add 0.231 grams (23.1% of 1 gram) to the water. To get 1 gram of nitrogen you would need to work out the ratio between the amount of ammonium sulphate and the amount of nitrogen present in the ammonium sulphate. This can be done by dividing the molecular weight of ammonium sulphate by the weight of nitrogen found in the ammonium sulphate as follows: 132/28 = 4.7

This means that to obtain 1 gram of nitrogen you would need to add 4.7 grams of ammonium sulphate to the 1,000 litres. This conversion factor of 4.7 remains constant for the supply of nitrogen using ammonium sulphate as a source, so that if you wanted for example a solution containing 200 ppm of nitrogen you would simply multiply 200 x 4.7 to give 940 grams of ammonium sulphate being required to go in 1000 litres of water. This technique can be used just as simply for the other chemicals used in hydroponics stock solutions.

Mixing Nutrients

In many instances, the total nutrients are supplied as a single mix (either in powdered form, or pre-dissolved in solution. These are obviously the easiest to work with, however, in some instances the solution is delivered as two or three separate components, each one mixed into the system from separate holding tanks.

Some nutrients used in NFT will react together, causing precipitation. For this reason, operations may need to use two or three different tanks, each containing separate and different stock solutions which when mixed together in a predetermined ratio, will produce a balanced nutrient solution. For example, salts which are not very soluble such as calcium phosphate or calcium sulphate tend to precipitate out of solution very easily. A typical situation might involve three tanks:

- One containing calcium nitrate
- A second containing most other nutrients
- A third containing diluted acids (which might be a source of nutrients such as nitrogen and potassium).

Hydroponic Fertiliser details

The most commonly used fertilisers in most basic hydroponic nutrient formations or recipes contain the following fertiliser salts: calcium nitrate, potassium nitrate, mono-potassium phosphate, magnesium sulphate, iron chelate (EDTA or similar), boric acid (or borax or solubor), manganese sulphate, zinc sulphate, copper sulphate, and ammonium molybdate (or sodium molybdate).

In some circumstances the sulphate trace elements (manganese, zinc, copper) may be supplied in the chelate form rather than as sulphates, however the cost of this is substantially higher than using the sulphate forms. Fertilisers may be obtained from horticultural suppliers, hydroponic retailers, or online. Small volumes of trace elements may be obtained from analytical chemical suppliers. The main fertilisers of calcium nitrate, potassium nitrate, mono-potassium phosphate and magnesium sulphate are typically purchased by the 20-25kg bag while iron chelate may be sold in 5-10kg packs. Most trace elements are sold by the kilogram or in smaller pack sizes. Fertilisers should always be purchased from reliable suppliers and reputable brands are preferable since chemical contaminates can cause considerable harm in hydroponics.

Calcium nitrate – this fertiliser typically provides 15.5% Nitrogen and 20% Calcium. Calcium nitrate is a white to off-white pale coloured prill (pellet or globule) which is highly soluble in water. Calcium nitrate must be stored correctly in an airtight container as it rapidly absorbs moisture from the air if stored incorrectly.

Potassium nitrate – is a white crystalline powder which provides 13% Nitrogen and 37% potassium however these values may vary from brand to brand. Potassium nitrate may also be called saltpetre and water soluble.

Mono-potassium phosphate (MKP) – is a white crystalline powder which provides 25% potassium and 21% P however brand may differ slightly in composition.

'Yara' and 'Haifa' are commonly used commercial manufacturers of calcium nitrate, potassium nitrate and mono-potassium phosphate fertilisers.

Magnesium sulphate (Epsom salts) – is a fine white crystalline fertiliser which typically contains 9-10% magnesium (Mg). It is highly soluble and readily available in a number of brands.

Iron chelate – iron chelate may be obtained as iron EDTA, EDDHA or DPTA. Iron (Fe) must be supplied in hydroponics as chelated iron rather than as iron sulphate which is unstable in nutrient solutions and tends to form iron hydroxides which are insoluble. Iron chelates protect the iron at higher pH levels. Iron chelates range in Fe content from 6-14% depending on product. Most iron chelates are a tan/yellowish to brownish fine powder. Iron EDTA is best used in nutrient solutions where the pH stays within the 5-6 range, whereas iron DPTA can be used where pH levels may raise higher.

Manganese sulphate – magnesium sulphate typically provides 24% manganese (Mn), however different brands can vary considerably in Mn level. Manganese sulphate is a white to pale pinkish powder.

Zinc sulphate – zinc sulphate often provides around 23% zinc (Zn) but may vary slightly between suppliers. Zinc sulphate is a white powder.

Copper sulphate – copper sulphate is a bright blue fine, manganese, crystalline fertilizer. Copper (Cu) levels are usually 25% but may vary slight between suppliers.

Boric acid/borax – boron (B) may be supplied as either boric acid (18% B) or sodium borate (borax). Solubor is another form of boron fertiliser. These are white powdered fertilizers.

Ammonium molybdate/sodium molybdate – sodium and ammonium molybdite are used to supply molybdite (Mo) and are in the form of white powders. Ammonium molybdate provides 48% Mo whereas sodium molybdite provides 39% Mo.

Chelated trace elements – apart from iron, which must be supplied as iron chelate, the sulphate trace elements of zinc, manganese and copper can alternatively be supplied as chelated fertiliser products. A chelating agent forms a complex which is resistant to reaction in solution and thus can assist with availability of a trace element for plant uptake under certain situations (such as high pH levels). The most widely used chelation agent for hydroponics is EDTA (ethylene-diaminetetraacetic acid). EDTA is less effective at high pH than the other chelating agent EDDHA. During uptake of the chelated trace element ion, the chelating agent is dissociated and can return to solution where it interacts with other trace element ions. Other chelation agents of organic origin include citric acid, humates and fulvic acid complexes.

CHAPTER 4 OTHER ADDITIVES

There are things other than just nutrients and water that can sometimes be added to the nutrient solution, in order to help along plant growth. In some instances these additions may be important.

Introduction

Legumes such as peas and beans will grow optimally in hydroponics utilising the plentiful nitrogen provided in the nutrient solution. While they may also naturally develop the root nodules containing nitrogen-fixing bacteria which soil grown crops form, these are not essential for hydroponic crops. Inoculation of hydroponic systems with mycorrhiza for N fixation and N nutrition is thus not required for hydroponic production of legume crops, however root nodules often form naturally anyway as these bacteria may be naturally present on seed, ion water supplies and in the growing environment.

Manual Home Hydroponic kit. Two bottles of nutrients need mixing to create a complete, balanced solution.

One situation where nitrogen-fixing crops are highly beneficial is with organic hydroponic systems where chemical sources of nitrogen such as calcium and potassium nitrate are not permitted. In these 'hydro-organic' systems nitrogen can be limiting under rapid growth rates. Legume crops, with their ability to obtain additional N through the association with Rhizobium species are thus a good choice for organic systems. While these bacteria do occur naturally in many hydroponic systems, with legume crops in organic systems the plants can be inoculated with the correct species of nitrogen-fixing bacteria which are widely available as microbial productions or incorporated into seed coatings. The root nodules that form on hydroponic legume crops are visible and appear as knobbly, rounded growths which can reach the size of a pea, firmly attached to the root system – these have sometimes been mistaken for root pathogens or other diseases by inexperienced growers, but are a perfectly natural occurrence.

The use of systemic pesticides in the nutrient solution is illegal in many countries and may lead to unacceptable residues in the produce being grown. Due to the fact that many pesticides, fungicides and other agrochemicals used for pest and disease control may react with the elements in the nutrient solutions it is not advisable to use these products in this way. Foliar spray application of pest and disease control products, following label instructions for rates and usage and only applying spray compounds registered for use on the crop being grown must be followed by all growers. In hydroponic systems care also needs to be taken when spraying pest or disease control products onto crop foliage as excess run-off may end up in the root zone and nutrient solution. This can create a contamination issue and may lead to traceable illegal residues in food crops.

Allowable Additives for Hydroponic Nutrient Solutions

A number of different additives and supplements may sometimes be used in hydroponic nutrient solutions. However, it is important to consider the role and functions of such additives before application and to ensure that none of them pose a potential plant toxicity or food safety risk. In solution culture, the addition or organic additives (those containing large amounts of carbon) should be treated with caution as these can provide a food source for microbial life, some of which may not be beneficial. Addition of large amounts of carbon-containing additives can also increase the BOD (biological oxygen demand) of the nutrient solution, thus reducing dissolved oxygen (DO) available for root uptake.

Humates (humic and fulvic acids)

The beneficial effect on plant growth of adding the correct humic substance has been known for a number of decades. These compounds are not only effective in soil grown crops, but also in various potting mixes and hydroponic systems. Application of humic substances to soils naturally low in organic matter, or hydroponic systems, seems to produce the most significant growth enhancement effects. Humic compounds can be absorbed by plant roots and transported to the shoots, thus enhancing the growth of the whole plant. In hydroponic tomato plants, it has been found that humic acid application resulted in higher root fresh weights and dry weights, as well as higher levels of certain mineral elements in the shoots and roots than those plants grown in nutrient solutions without humic acid. This same effect has been found in other hydroponic crops.

Studies on the effects of humic acid on plant growth under conditions of adequate mineral nutrition consistently show positive effects on plant biomass. Humic acids increase soil and plant productivity by enhancing the uptake of essential nutrient elements through chelation and increasing plant growth through their effect on root enzymes and the soil. Both increases in root length and stimulation of the development of secondary roots have been observed for humic acid in nutrient solutions, soils and growing mixes. The stimulating effect of humic acid has been correlated with enhanced uptake of nutrients. Humic acid has also been found to increase photosynthesis in some plant species, thus enhancing the growth of the whole plant. Humic acid has been widely proven to have beneficial effects on plant growth over a wide range of concentrations with application as a soil/media drench, seed soak and nutrient solution additive.

Fulvic acid is one of the many chemical compounds that qualify as humates, and it appears to be more biologically active than humic acid. Fulvic acid has direct effects on membranes resulting in improved transport of nutrients, enhanced protein synthesis, possible plant hormone-like activity, and enhanced photosynthesis. It also has indirect effects such as solubilisation of micro-elements (Fe, Zn, Mn), as well as some macro-elements (K, Ca, P), reduction of active levels of toxic elements, and enhancement of microbial populations.

Humate products are available in a number of different forms for use in hydroponic nutrient solutions however selection of water soluble fulvic acid products is most commonly used in solution culture. Humate additions are typically available as either a water soluble powder or a liquid concentrate ready for dilution and dosing directly into the hydroponic nutrient solution. These products are often incorporated into other organic additives and organic fertiliser concentrates. There is some evidence to suggest that combining humates with other crop bio-stimulates such as seaweed extracts or amino acids can provide further growth benefits, although it is somewhat dependant on the method of application, the concentrations used, and the crop species grown.

Surfactants

Apart from their common use as spray additives and wetting agents, non ionic surfactants have two major potential uses in hydroponic nutrient solutions. The first has been known since the 1960's, which is the fact that non ionic surfactants have the ability to kill pathogen zoospores and control the spread of certain root rot diseases in the nutrient solution. The second is a more recently reported effect of surfactants in boosting plant growth in some species under hydroponic conditions.

The control of disease zoospores in hydroponic nutrient solutions by non ionic surfactants was actually discovered by accident when researchers applied a fungicide containing a surfactant to a hydroponic lettuce crop. It was discovered that the synthetic surfactant in the fungicide was effective in destroying the zoospore plasma membrane, thus reducing the ability of the spores to move and infect plants, eventually killing them. While non ionic surfactants had little or no effect on any other stage of the disease life cycle (which have cell walls rather than plasma membranes), in killing or retarding the zoospores in the nutrient solution the potential for the control of these root infecting pathogens was realised.

Further studies were carried out on a number of different hydroponic crops which were prone to zoosporic fungal disease outbreaks. Most found highly promising results in that non ionic surfactant used at the correct rate could give a high degree of disease control of Pythium and Phytophthora in the nutrient solution. However, while the surfactant could destroy large numbers of zoospores being carried by the nutrient solution, hence prevent or slow the spread of these diseases, it had no effect on plants already infected when the disease was present inside plant tissue. Thus use of non ionic surfactants in the nutrient solution is more of a preventative action rather than curative – it destroys zoospores released by active disease outbreaks and prevents these from infecting new plants.

In order to be effective, the correct rate of non ionic surfactant product needs to be continually maintained in the nutrient solution. When this is achieved growers have reported good results. Many of the newer bio-surfactant products designed for hydroponic use include dose rates on the product label which should be carefully followed. As with most products and compounds available as nutrient solution additives, over-dosing does not give better results. In many cases, it can be quite toxic to the plants. Another issue concerning dose rate is that surfactants are gradually broken down by microbial action over time. Determining how often to re-dose may be difficult and require some trial and error.

There are other issues with potentially beneficial additives growers should be aware of. For example, some growers who found non ionic surfactant useful for the reduction of root rot pathogens such as Pythium also reported foaming in the nutrient reservoir was common, particularly in the first few days after the surfactant was added. Foaming is to be expected when what is essentially a strong detergent is added to moving water however the degree of bubble formation differs between surfactant products.

Beneficial trace elements

One area of interest to hydroponic growers has always been the use of 'beneficial' mineral elements which are those outside the range of the essential macro and micro nutrients required by most of the plants we grow. While science has identified a total of 17 essential elements (N, P, K, Ca, Mg, S, Cl, Fe, Mn, Zn, Cu, B, Mo, Ni, O, C, H) required by plants for growth, plant matter has been found to contain over 60 elements as diverse as titanium, gold, mercury, arsenic, uranium, sodium and many others. Since plants evolved in soil, they developed the ability to make use of a number of substances and elements, which while not essential for plant growth, have been shown to enhance growth, development and other functions.

Selenium

While selenium (Se) enrichment of food crops for human health benefits has been an area of recent study, selenium may also have a beneficial role in plant growth and development. Plant tissue contains less than 1ppm of Se in most species however selenium is chemically similar to sulphur, a plant macro element, and appears to be metabolised via the same mechanisms. Trace amounts of Se have been found to stimulate growth in a variety of plant species including ryegrass, lettuce and potato and to also provide the plants with more resistance to ultraviolet radiation. There is also evidence that boosting Se levels in hydroponically grown plants can help protect from biotic stress such as fungal diseases.

Cobalt

Cobalt (Co) concentrations in plants are typically in the range 0.1-10ppm on a dry weight basis and cobalt is often found in low levels in natural water sources (0.04ppm). At low levels, cobalt can have a number of beneficial effects, particularly in leguminous plants such as peas where application of Cobalt increases growth, nodule number and weight, as well as seed pod yield and quality. Cobalt may also play a role in slowing leaf aging and in disease resistance in some species.

Since cobalt is also essential for human health, addition of this element to nutrient solutions can enhance the nutritional quality of hydroponic food.

Titanium

Titanium (Ti) is another element whose role in plant development and metabolism has been studied for over 90 years. While plant tissue is generally low in Ti content, being 0.1-10ppm on average, titanium is present in soil in relatively high concentrations. Studies have found that the chlorophyll content of hydroponic tomato plants increased when titanium was added. When maize was provided with titanium in solution the yield increased, and the concentration of sugars in the grain also rose.

Iodine

Another interesting potentially beneficial element is iodine (I). Iodine has been found to stimulate the synthesis of cellulose and the lignification of stem tissue that helps the mechanical strengthening of the plant. Iodine has been found to increase the concentration of ascorbic acid in plants and the amount of total free amino acids in crops grown in solution culture. Iodine also seems to increase salt tolerance in plants by facilitating a lower chlorine uptake.

Silicon

Silicon (Si) is a very common element and comprises more than 25% of the earth's crust. Si is mostly available to plants as monosilicic acid, $Si(OH)_4$, which is taken up from the soil water. In fact, the concentration of silicon in soil is equal to that of many macronutrients such as potassium and calcium and well in excess of phosphate levels. Once inside the plant silicon is deposited as amorphous silica throughout the plant mainly in cell walls. After silicon has been incorporated into plant tissue it cannot be redistributed through the plant so it needs to be in constant supply if the entire plant is to contain a useful amount.

The role of silicon in plants is multifunctional. It contributes to strength and thickness of cell walls which helps to keep plants upright and to position their leaves for good light interception. It plays a role in resistance to attacks by fungi and insects and provides greater tolerance to plant 'stressors' such as high salinity or heavy metal toxicity, drought, UV radiation from sunlight, and extremes of temperature. Several plants actually require silicon as an essential element including rice, sugar cane and tomatoes, while a large number of other species have shown growth benefits including increased absorption and translocation of several macro and micro nutrients.

The use of soluble and slow release forms of silicon as a hydroponic additive is not new. Many cucumber and rose growers are well aware of the benefits of adding silica to the nutrient solution, whether it is in organic or non organic form. Silica in cucumbers, for example, reduces the incidence and severity of powdery mildew and other fungi. Enrichment of the nutrient solution with silicon in hydroponic strawberry crops resulted in a greater number of fruit produced compared to control plants which received no additional silicon. However, silicon in solution should not be considered to be a trace element. Levels as high as 140ppm have been shown to have the most significant effects since silica is naturally found in many plant tissues at up to 10% or higher (dry weight).

Beneficial Trace Elements as Hydroponic Additives

Many water sources, particularly well water, already contain a range of the additional elements found in plant tissue however the levels and types of elements vary depending on the location and soil type. Some beneficial elements also find their way into hydroponic nutrient solutions from dust or tiny amounts of soil contamination and from growing media but growers can intentionally boost these levels by supplementing their nutrient solution. In the early days of hydroponics some growers added small volumes of soil extract or sea water to their nutrient solution to provide a diverse range of micro elements, however since seawater contains large amounts of sodium chloride issues often arose with salt accumulation. There are now far more advanced ways of adding the beneficial elements we want, and excluding those we do not want.

Some of the more widely known beneficial elements such as silica have been available to hydroponic growers for many years and have even been incorporated into nutrient products or developed as an additive. More recently, certain beneficial elements such as selenium and chromium have also been included as additives in some nutrient products. While it's not practical for a hydroponic grower to be able to obtain and weigh out the extremely tiny quantities of the pure salts of these elements, large scale manufacturers of nutrient formulations and hydroponic additives can do this with a high degree of accuracy and ensure growers are using the correct levels of these elements. As a simpler approach, there are other hydroponic additives which contain the minute amounts of many beneficial elements, and most of these are organic or mineral based. Seaweed concentrates, for example, contain a large number of the potentially beneficial elements, as can concentrated vermicast (worm casting) extract, organic nutrients, mineral clay supplements, and a number of other products developed for the hydroponic market.

Bio-stimulants as Hydroponic Additives

A plant bio-stimulant is defined as "*an organic material, that, when applied in small quantities, enhances plant growth and development such that the response cannot be attributed to application of traditional plant nutrients*."

Plant bio-stimulants are a category separate from the synthetic plant growth regulators, although there can be some overlap with certain compounds. Generally, synthetic plant growth regulators are those such as auxins, gibberellins, cytokinins and ethylene which have well known uses in horticulture such as for root formation, fruit set, fruit ripening and others. Bio-stimulants may have similar modes of action, however many have numerous other roles involved in disease resistance, chelation of mineral ions, stress resistance, metabolic enhancement, promotion of microbial populations and regulation of certain physiological and biochemical processes in plants.

While bio-stimulants may seem like compounds only destined for high tech production of valuable crops, many are readily available on the market. These are often found as additives to fertiliser products or as standalone products for widespread crop production. Triacontanol is used as a fertiliser additive, humic and fulvic acids can be purchased as standalone products, amino acids are becoming increasingly popular and various forms of seaweed products can be purchased for use in nutrient solutions or as foliar sprays.

Amino acids

Amino acid plant bio-stimulant products and additives are relatively new and not well understood by many growers. There have been conflicting results in the scientific literature as to the effectiveness of amino acid supplements on crop growth and much of this may stem from the differing composition of amino acid products on the hydroponic market. Amino acids are the building blocks of proteins with the L-amino acids having metabolic activity. Unlike the other bio-stimulant compounds there are a number of different amino acids, and some appear to be more biologically active than others.

Most of the amino acids used as plant growth stimulators are derived from hydrolysed proteins such as soy. Some of the amino acid mixtures which have been tested contain alanine, aspartic acid, glutamic acid, glutamine and glycine, although other mixtures contain different amino acids and it appears the degree of protein hydrolysis, free amino acid (AAL) content and molecular weight determine the specific activity of amino acid mixtures.

Scientific studies into the effects of amino acids on plant growth are mostly relatively new, having only been carried out over the last two decades or so. Some of these have found that certain amino acids can directly and indirectly influence the physiological activities of plants. Amino acids may be applied to foliage where they are absorbed through the stomas, although this is dependent upon the temperature at the time of application. Amino acids may also be supplied to plants by incorporation into the growing substrate or hydroponic nutrient solution where they benefit the micro flora and improve nutrient availability and assimilation.

One recent study found that application of mixed amino acids to red pepper increased NO_3 uptake by seven times higher than the untreated control. Other researchers have claimed that amino acids have an effect on photosynthesis, protein synthesis, lignification, resistance to abiotic stress and have a hormone like activity. While amino acid supplements which have been specifically designed for hydroponic use are commercially available, these should be used strictly at label recommended rates. Over-application of amino acids can result in rapid microbial population increases which can increase the biological oxygen demand in the system and result in a lack of dissolved oxygen for root uptake.

Salicylates

Salicylic acid is known to be present in a wide range of plants and is considered to be a plant growth substance which has been shown to have an effect on a variety of plant processes, including flowering and promotion of disease resistance. There is evidence to suggest that salicylic acid exhibits plant hormone-like activity as it acts at very low concentrations and can be transported within the plant to sites of attack by disease pathogens. There have been conflicting reports from scientific studies indicating that salicylic acid can stimulate flowering on a number of crop species and the evidence on this is still inconclusive.

Salicylic acid is best known for its ability to induce disease resistance in many plants. Resistance to pathogens and the production of some 'pathogenesis-related' proteins can be induced by application of salicylic or acetylsalicylic acid which then provides resistance to subsequent disease infection. Despite these findings, research still continues into the possibility of using salicylic acid as a natural disease response elicitor in commercial crops. Salicylic acid is most commonly applied via foliar sprays but it can also be directly dosed into the hydroponic solution using the correct compound and dose rate.

Seaweed and naturally occurring cytokinins

As early as the 1960's researchers found that naturally occurring cytokinins in seaweed could provide a growth stimulator effect, however the results were often unpredictable and inconsistent as different seaweed sources had varying levels of cytokinin. Stable extracts of seaweed of certain species have been shown to improve root and shoot growth and improve stress resistance in some crops by increasing the endogenous natural production of antioxidants in the plant. Seaweed products also contain a wide range of minerals, and although some of these are not essential for plant growth they are known to be beneficial for growth, development and disease resistance.

Foliar Nutrition and Foliar sprays

Although hydroponic crops may appear to be supplied with optimal nutrition via a well-balanced and formulated nutrient, they still benefit from the application of foliar fertilisers. The most widely applied method of plant fertilisation is through the root system either via the soil or inorganic media substrates such as those used in hydroponic production. While plant root systems are in the most part efficient at absorbing mineral nutrients, certain conditions can prevent optimal uptake rates of some of the elements plants require. Foliar feeding provides nutrients through the foliage of the plant which has the ability to absorb and translocate certain minerals within plant tissues.

In hydroponics, many nutrient interactions can occur within the root zone which makes it difficult for the plant to absorb certain minerals. Soils and even hydroponic systems can become deficient in nutrients because of nutrient depletion, antagonism between certain elements, naturally low nutrient levels, inadequate fertilisation, or due to elements becoming 'bound' and therefore unavailable for plant uptake. Imbalances in the combination of nutrients, pH levels which are too high or low for maximum plant uptake, and poor physical properties of the media surrounding the root zone, including oxygen starvation are more common in soilless systems than many growers realise. Furthermore, elements such as iron, which is an essential trace element, are not only prone to become unavailable for plant use at moderate to high pH levels, but their uptake by the plant is also severely limited under certain environmental conditions like cool temperatures. Iron chlorosis in many crops which are stressed by low temperatures can be a common problem where root uptake is the only source of iron for the plant.

Any situation which damages the root system or restricts its growth, development or physical processes such as respiration will affect the uptake of minerals. Plant pathogens such as fusarium, pythium and phytophthora can rapidly destroy a crop, but even at less damaging low levels they can restrict functioning of the root zone to the point where mineral uptake is affected. While the crop may not show signs of severe infection, mineral and water uptake can be restricted to the point where crop yields and quality are affected. Other plant stressors such as anaerobic conditions in the root zone where oxygen is limited, can limit nutrient uptake with trace elements such as iron often affected to the greatest degree. Any other condition which stresses the plant like temperature stress, high or excessively low humidity levels, lack of light, high radiation levels, high plant densities, presence of pests or diseases, will affect the efficiency of the root system in taking up mineral elements. Many of these conditions are common and occur in many commercial production situations without the grower realising that plant growth and mineral uptake is being limited in some way. It is under these types of very common situations that foliar feeding has its greatest advantage. Since foliar absorption is limited because of the relative barrier of the cuticle it is not possible to solely feed plants via the leaves. For this reason the most effective use of foliar fertilisation is as a rapid and effective method of supplying the micro nutrients. It can, however also be used to satisfy acute needs with lower concentrations of macronutrients.

Application of foliar feeding sprays

The addition of a wetting agent or surfactant is vital to the application of foliar fertilisers. Wetting agents are necessary to ensure the adherence of droplets on difficult to wet leaves as well as assisting with the absorption of the fertiliser solution into the plant tissue. Foliar feeding sprays are best applied in the early to mid morning period of the day when stomata are fully open, thus absorption rates highest. Testing a new foliar spray on a few plants first, then waiting a few days to determine if spray damage is likely to occur is an important step since greenhouse and indoor crops in particular may have a thinner cuticle than those grown outdoors and be more prone to spray damage. Most foliar sprays are applied once weekly or less frequently depending on use. Spray should be applied in a fine mist to run off, however avoidance of any run off soaking into the growing substrate and contaminating the nutrient solution is recommended with hydroponic systems.

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CHAPTER 5 CREATING HYDROPONIC NUTRIENTS

There are different ways of creating hydroponic nutrient mixes from simple ready mixed nutrient formulas which simply require diluting, through to weighing out each ingredient yourself.

Introduction to Basic Mixes

The basic mixes below from the 1950s are interesting from a historical perspective, but are not really suitable these days as hydroponic nutrient solutions. The creation of nutrient solutions has come a long way since the early days of hydroponics as we have increasingly understood the complex issues created by factors such as solubility, availability and toxicity characteristics of different forms of nutrients. Nevertheless, an appreciation of the evolution of nutrient solutions can help to inform your overall knowledge.

Tissue Culture

Basic Mixtures from Early Hydroponics

The following mixes are taken from "*The Bengal System, 5th Edition*" by James Sholto Douglas published by Oxford University Press, 1959.

Basic nutrient mix used in India in the 1950s

- 12.5 ounces of sodium nitrate
- 7 ounces of superphosphate
- 4 ounces of potassium sulphate
- 4 ounces of magnesium sulphate
- Plus ½ a dram of trace elements made up of: zinc sulphate, manganese sulphate, boric acid powder, copper sulphate and iron sulphate

Second Basic Mixture
(1 ounce equals 16 drams)

- 8 ounces ammonium sulphate
- 5.5 ounces ammonium phosphate
- 3 ounces muriate of potash
- 2 ounces calcium sulphate
- 4 ounces magnesium sulphate

Plus ⅓ dram of trace elements made up of: zinc sulphate, manganese sulphate, boric acid powder, copper sulphate and iron sulphate

Third Basic Mixture

- 10 ounces ammonium sulphate
- 2.5 ounces potassium sulphate
- 6 ounces superphosphate
- 3 ounces magnesium sulphate
- Plus ⅓ dram of trace elements made up of: zinc sulphate, manganese sulphate, boric acid powder, copper sulphate and iron sulphate

A Trace Element Mix

- 3 drams of zinc sulphate
- 9 drams of manganese sulphate
- 7 drams of boric acid powder
- 3 drams of copper sulphate
- 10 drams of ferrous or iron sulphate

Note: 1 ounce = 16 drams
1 ounce = 28.349 grams

The above powdered nutrients need to remain dry in storage. If they get just slightly damp, the nutrient status can change as chemicals interact.

Plants will use more potassium in dull or overcast weather. Also, nitrogen can be reduced slightly in dull weather as it is only used in optimal amounts in bright sunny conditions.

If water becomes very alkaline, a little sulphuric acid may be added to balance pH; but never more than one quarter of a fluid ounce per 100 gallons. Very acid water can be treated similarly with a dilute alkali (lye). Never pour water into acid or alkali because it is dangerous. Always add the chemical to the water.

Note: 1 US gallon = 3.785 litres
1 imperial gallon = 4.546 litres

Process of Making and Mixing Nutrients from Fertiliser Salts

As time moves forward and we learn more and more about plant nutrition dynamics, the way we create nutrients has changed, and will very likely continue to change. Older references can be enlightening but be cautious about using old formulae that may very likely be less sophisticated and less effective for growing plants.

For growers who wish to make their own nutrient formulations from a customised ‘recipe’ the mixing process is relatively simple. The nutrient formulation needs to be balanced and suitable for the crop, water supply, environment and system and there are many examples of ‘base recipes’ found in books and professional nutrient formulation software.

Some care needs to be taken when considering a nutrient formulation to use. For instance, growers should ensure that all the essential elements are contained in the recipe (N, P, K, Ca, Mg, S, Fe, Mn, Zn, B, Cu, Mo) unless levels are high enough in the water supply to meet plant requirements, and that they fall within the recommended ranges for each.

Preparing a Solution

The process of mixing up a formulation for a nutrient recipe involves carefully weighing out the fertiliser salts, placing them into the stock solution containers, then adding sufficient water (warm water will speed up the process) up to the volume mark. Because the fertiliser salts themselves take up volume, a 100 litre stock solution will require less than 100 litres of water to reach the 100 litre volume mark. Once mixed and stirred, the salts will start to dissolve and these stock solutions once covered and in light-proof containers will keep indefinitely.

A simple means of preparing a nutrient solution is as follows:

- First, weigh nutrient chemicals individually. It is worth investing in digital scales which can weigh down to one hundredth of a gram.
- Lay the chemicals out in separate piles on sterilised filter paper, or in plastic trays or measuring cups. Visually inspect each, noting the colour of the chemical and relative sizes of the amounts.
- Ensure the proportions make sense and no mistakes have been made. Be particularly careful that no chemical component is left out or measured twice.
- Weighing should be as accurate as possible, especially for micronutrients. There is a little more leeway with macronutrients which can be accurate within plus or minus 5% (within this range the effect on plants will be negligible).
- Partly fill the nutrient solution tank with water.
- After all this has been done, add each nutrient into a bucket of water and vigorously stir until dissolved (ensure you have enough water to dissolve the amount of chemical). Then add to the tank. Alternatively, you can add the chemicals directly into the tank and stir until dissolved.
- The order in which the chemicals are added is unimportant, but it is extremely important to thoroughly dissolve any less soluble salts. There will always be some material which doesn’t dissolve completely but this is generally not enough to be significant.
- After mixing the nutrients the pH may need adjusting (see the section on pH).

Micronutrients, and particularly iron, are added *after* pH is adjusted in the solution because they can be precipitated out of the solution at higher pH levels of 7 or more and become unavailable to plants. Once the pH is in the desired range (5.5 to 6.5) you can add the micronutrients.

Example Solutions

The following solutions give an indication of the types of combinations of chemicals that are commonly used. Typically, stock solutions are made first. These are concentrated solutions which are diluted for use in the hydroponics system. How concentrated the stock solutions can be is limited by the solubility of the salts included in them i.e. the least soluble salt. Usually, nutrient formulations are divided into two solutions e.g. Part A and Part B stock solutions.

Example One

All quantities are based on using pure water. Two concentrated stock solutions can be made up as shown below:

SOLUTION 1	*To 100 litres of water add:*
Calcium nitrate	7,500 g
SOLUTION 2	*To 100 litres of water add:*
Potassium nitrate	9,000 g
Potassium dihydrogen phosphate	3,000 g
Magnesium sulphate	6,000 g
Iron chelate EDTA	300 g
Manganese sulphate	40 g
Borax	37 g
Copper sulphate	8 g
Zinc sulphate	4 g
Ammonium molybdate	1 g

Note: It is important to ensure that the correct volume of water is used to make the concentrated stock solutions because it allows the salts to dissolve fully. If the volume of water is too low the solution will become saturated and some salts will not dissolve properly. For different volumes of solution the recommended proportions of chemicals should remain the same. So, to make 10 litres of each stock solution simply divide the amount of each salt by 10, and so forth. Hot water can be used to expedite the mixing process and is particularly useful for salts which are difficult to dissolve.

Why Two Stock Solutions?

Two solutions are needed and must be kept separate in the concentrated state so that reactions don't occur which make some elements unavailable for plant uptake. For example, fertilisers containing calcium will react with any containing phosphate or sulphate. Therefore, using the chemicals in example one above, calcium nitrate will react with potassium dihydrogen phosphate in a stock solution to form calcium phosphate. This will precipitate out of the solution and fall to the bottom of the tank or container holding the solution, where it forms sludge. The majority of the calcium and phosphate in the stock solution becomes unavailable to the plants and the insoluble calcium phosphate sludge may block irrigation lines and nozzles. Likewise, calcium nitrate in a stock solution will react with magnesium sulphate and copper sulphate, and calcium sulphate will precipitate out of the solution. The majority of other chemicals commonly used in stock solutions can be mixed together, however care should be taken when using previously untried formulations that precipitation doesn't occur.

Dilution

Each concentrated stock solution should be diluted to 1 in 100 to prepare it for use. *Do not mix the concentrated stock solutions.* When you are ready to apply the nutrient solutions, this is the time to mix the diluted stock solutions. To do this you would add 1 litre of the first stock solution to 100 litres of water in a tank. You can then do the same for the second stock solution.

When you do this, provided that the pH is in the normal range, the precipitation reactions between calcium and sulphates or phosphates will not take place because the relative volumes of these chemicals in the diluted solutions are not enough.

In commercial operations, stock solutions are introduced to the system using a proportioner or injector. These save the labour involved in diluting stock solutions. A proportioner is an electronic or mechanical device which is connected to a stock tank. One proportioner is needed for each tank, unless it has separate inlets fed from each tank. This device adds stock solution into the main irrigation line at a specific rate. If, as in our example, the stock solution is to be diluted to 1 in 100 then the proportioner can be set to add 1 litre of stock solution for every 100 litres of water that flows through the main pipe.

Various automated nutrient supply systems are commercially available.

Example Two

This is a basic vegetative tomato formulation for use when growing from seedlings until fruit set using high quality (RO) water sources. The recipe gives the amount of fertiliser salts to dissolve into two 100 litre stock solution (concentrate) tanks. Using a 1 in 100 dilution rate will give an EC of 3.0 mS/cm and TDS (total dissolved solids) of 2,100.

PART A	
Calcium nitrate	15,123 g
Potassium nitrate	3,453.7 g
Iron chelate (20%)	500 g
PART B	
Potassium nitrate	3,453.7 g
Mono-potassium phosphate	3,303.4 g
Magnesium sulphate	6,828 g
Manganese sulphate	80 g
Zinc sulphate	11 g
Boric acid	39 g
Copper sulphate	3.02 g
Ammonium molybdate	1.02 g

When diluted to an EC of 3.0, it will give the following nutrient levels in solution:

N = 324 ppm

P = 69 ppm

K = 352 ppm

Mg = 67 ppm

Ca = 302 ppm

S = 89 ppm

Fe = 5 ppm

Mn = 1.97 ppm

Zn = 0.25 ppm

B = 0.70 ppm

Cu = 0.07 ppm

Mo = 0.05 ppm

Note: This formulation should be adjusted as the crop goes through differing levels of fruit loading to include higher ratios of potassium.

The formulation is designed for a high quality, pure water source such as reverse osmosis (RO) water and should be adjusted for the presence of any elements present in other less pure water supplies. The recommended pH level for this formulation is 5.8 and an EC of 3.0, which is dependent on the season and cropping system. Potassium nitrate in this formula is split between the A and B stock solution tanks to prevent problems with solubility i.e. potassium nitrate is the least soluble fertiliser amongst the ingredients so splitting it between the tanks means it is more likely to dissolve completely.

Example Three

The third example presented here is a widely used formula in the United States. It is one devised by Hoagland and Arnon at the University of California.

CHEMICAL	*Grams per 1,000 litres of water*
Calcium nitrate	1,181.0
Potassium nitrate	505.5
Monopotassium phosphate	136.1
Magnesium sulphate	493.0
ALTERNATIVE FORMULATION	
Calcium nitrate	1,181.0
Potassium nitrate	505.5
Monoammonium phosphate	115.0
Magnesium sulphate	493.0

To both formulations are added a trace element solution comprising the following:

CHEMICAL	*Grams to make 1 litre of stock solution*
Boric acid	2.86
Manganese chloride	1.81
Zinc sulphate	0.22
Copper sulphate	0.08
Molybdic acid	0.02

The quantities described in this formula will provide sufficient stock to make 1,000 litres of the dilute nutrient solution. An iron stock solution is also required. This should contain 1 gram of actual iron per litre of stock solution. One litre of iron stock is sufficient for 1,000 litres of dilute nutrient solution.

Adjusting for Growing Conditions

Problems can occur when taking formulations from very different growing environments. For example, a low light mid winter formulation may not be ideal for a high light, rapidly growing summer crop. Vegetative and fruiting formulations for heavy cropping plants such as tomatoes and cucumbers should be used to allow for significantly higher potassium uptake during the fruit expansion phase. Similarly, when plants are making a lot of leaf growth the nitrogen requirements are generally higher than when the plant is fruiting.

Checking the nitrogen source in formulations is also advisable since the ammonium form of nitrogen is different from the nitrate form. Low levels of ammonium based nitrogen (less than 15% of total nitrogen) are generally acceptable to help boost winter growth of vegetative crops and help control pH rise, but too much ammonium (NH_4) competes for calcium uptake and can increase problems such as blossom end rot (BER) and tip burn under certain growing conditions. High levels of ammonium can also cause plant toxicity.

Example Four

The following example is a hydroponic nutrient formation for NFT arugula crops using RO water for winter growth. A dilution of one in 100 will give an EC of 1.6 and TDS of 1120 (*reference: L Morgan, Suntec International Hydroponic Consultants*).

STOCK SOLUTION A (50 LITRES)	
Calcium nitrate	4,010 g
Potassium nitrate*	800 g
Iron chelate (10%)	179 g
STOCK SOLUTION B (50 LITRES)	
Potassium nitrate*	800 g
Mono-potassium phosphate	1,090 g
Magnesium sulphate	2,132 g
Manganese sulphate	41 g
Zinc sulphate	5.5 g
Boric acid	19.5 g
Copper sulphate	1.5 g
Ammonium molybdate	0.5 g

** Potassium nitrate is split between the A and B stock solutions to assist solubility.*

This formulation would give the following ppm of each element at a 1:100 dilution rate:

Nitrogen = 166ppm, Phosphorus = 46ppm, Potassium = 179ppm, Magnesium = 42ppm, Calcium = 160ppm, Sulphur = 55ppm, Iron = 3.5ppm, Manganese = 2ppm, Zinc = 0.25ppm, Boron = 0.70ppm, Copper = 0.07ppm, Molybdite = 0.05ppm.

Note: This is just an example of a formulation showing a commonly used standard nutrient formulation for a vegetative crop and may not be ideal for all growing situations, systems and crops.

The above stock solutions are just some of the many solutions that have been developed for general use. They can be modified to some degree to be suitable for the majority of cultivated plants; some may require specific formulations.

Nutrient Solution Formulation

One thing that all nutrient formulations have in common is that they aim to supply the plant with all of the essential elements required in ratios close to what the plant will remove from the nutrient. This means that a nutrient formula not only supplies all of the plant's requirements, so that no toxicity or deficiency in any one element occurs, but also that ions are removed from the solution in the ratios in which they are continually supplied. So, over time the nutrient solution does not become imbalanced with higher rates of some ions than others, and this will maximise the useful life of a particular nutrient solution.

However, in reality this is difficult to achieve. Firstly, most nutrient solutions will suffer a build-up of some 'unwanted' ions over the long term, with sodium present in water supplies being the most common. Since most plants don't take up large amounts of sodium ions, accumulation occurs over time and replacement of the nutrient solution becomes necessary. Secondly, it is rather difficult to accurately predict nutrient uptake rates from any crop as this varies considerably depending on stage of growth, environment and even cultivar. A crop which may have a predicable nutrient uptake rate as a young seedling is likely to have a very different ratio of nutrient uptake as a flowering, fruiting or mature plant. This makes it necessary to use several different nutrient formulations during a crop's life span if the nutrient is to remain balanced and optimal for growth.

As such, many successful growers use a process of nutrient analysis and solution formula adjustment throughout the cropping cycle to maximise plant nutrition. If carried out correctly this will catch any problems with nutrient imbalance before plant growth and yields are affected. Few growers realise that although their crop may look good and seem to be yielding well, produce quality and yield increase can often be obtained with a good nutrient management program, rather than relying on one 'tried and true' formula for each crop at all stages of growth. Tomatoes and other fruiting crops are a typical example of this.

Hydroponic Nutrient Levels

Parts per million (ppm) is the commonly used measurement when comparing the different elements in hydroponic nutrient solutions (note that ppm is equivalent to milligrams per litre, mg/l). Below are some typical recommendations for most commonly grown hydroponic crops for elemental ppm values:

Table: Range of nutrient concentrations used in hydroponic systems

NUTRIENT ELEMENT	*Concentration (mg/litre or ppm)*
Nitrogen (nitrate)	70 – 400
Nitrogen (ammonium)	0 – 31
Phosphorus	30 – 100
Potassium	100 – 400
Calcium	150 – 400
Magnesium	25 – 75
Sulphur	50 - 120
Iron	0.5 – 5
Boron	0.1 – 1
Zinc	0.02 – 0.2
Copper	0.1 - 0.5
Manganese	0.5 – 2
Molybdenum	0.01 – 0.1
Sodium	depends on the crop

As you'll note, there is quite a wide range for each of these commonly used elemental ppm levels. There are a number of reasons for this. For instance, EC determines nutrient strength, so a tomato formulation run at an EC of 5.0 will have much higher ppm values of the macronutrients than a lettuce solution run at an EC of 1.0, just due to the concentration factor. Also, fruiting crops will have a considerably higher level of potassium (for fruit tissue development) than a vegetative-only crop. Furthermore, some elements like iron

(Fe) are varied based on environmental factors such as light. A high light environment will require a nutrient formulation with considerably more iron to meet plant demands under those growing conditions than a crop under short days of low light, for example.

Most commercial nutrient brands will be able to supply this information i.e. the ppm of each of the major and trace elements at certain EC values or dilution strengths. Using this information, growers can determine if the nutrient product meets their plant's requirements, or calculate the amount of other boosters they may need under certain situations. A common example is using a potassium booster in heavily fruiting crops to bring potassium levels up to plant requirements during this particular stage of growth. Fruit tissue contains large amounts of potassium, so this prevents potassium depletion, particularly in recirculating systems.

Nutrient Ratios

Changing the ratio of nitrogen (N) to potassium (K) between vegetative and fruiting crops is only a means of trying to match the different uptake ratios at these stages of growth. Using a 'bloom' formulation, for example, does not suddenly force vegetative plants to commence flowering and fruiting any more than using a 'summer' formulation produces fine weather. Instead, flowering and fruiting is determined by other factors such as maturity stage, day length, growing conditions, etc. The differences in formulae is simply to allow the nutrient solution to stay in balance longer while estimating the likely rate of removal of certain ions from the solution under certain conditions.

Not only do recirculating and non-circulating systems often have different nutrient formulations, but the growing medium also plays a role. Completely inert growing substrates such as rockwool or perlite do not affect the composition of the nutrient solution around the roots. However, freshly expanded coconut fibre, depending on pre-treatment and quality, does have a CEC (cation exchange capacity) and systems incorporating it often benefit from the use of a 'coco formulation' at least for the first few weeks of growth. Coco formulations are usually higher in nitrogen to help counter any initial nitrogen drawdown, higher in calcium and iron to help with calcium and iron retention in the medium, and lower in potassium which is a naturally occurring salt in many coconut fibre substrates.

One main reason why a grower might need to formulate their own nutrient solution is because the water supply contains minerals which need to be adjusted for. Common examples are calcium, magnesium and trace elements such as boron, zinc and copper which are only required in tiny quantities for plant growth. This practice is often undertaken by commercial growers who adjust their nutrient formulation for the presence of these plant usable minerals in the water supply, hence preventing build-up and accumulation which eventually causes solution imbalances. To carry this out, a water analysis is obtained to determine which minerals are present and at what levels (either from the municipal water supply authority or from an agricultural lab in the case of well water). The base formulation for the crop can then be adjusted to allow for this, thus reducing the need for certain fertiliser inputs. This process can be carried out using hydroponics formulation software programs.

Assessing a Nutrient Formulation

By starting out with a good basic nutrient solution for the crop being grown, and through a process of taking a solution sample for analysis on a regular basis, a grower can modify a formula to create the most ideal ratios for a particular growing system.

The suggested step-by-step procedure for any grower wanting to start formulating their own nutrients is:

1. Obtain a compete water analysis report of the raw water supply (treat water if necessary to removal ‘unwanted’ minerals such as sodium or high levels of trace elements).

2. Start with a good basic formula for the crop to be grown (many have been published in various sources, however try to select a formula which was designed to be used in a climate similar to what the crop will be produced in i.e. growers in high light/temperature regions would be best advised not to use a formula from a lower light region of the world).

3. Check to see if the formula has adjustments for seedling, vegetative, flowering or fruiting stages (or different seasons). If not, try to determine just what stage of crop the formula is for.

4. Check to see that levels of the nutrients supplied by the formula fall into the approximate ranges given in the earlier table (this can also be done for pre-made concentrate products).

5. Make up the formula carefully (be particularly precise when measuring out the trace elements as some of these are only required in very small amounts).

6. Use the formula to grow the plants. After 2, 4, and 6 week intervals take a solution sample (either directly from the system in the case of NFT or as solution leachate in media based systems) and have a complete analysis carried out. This can then be compared back to the initial mineral levels the formula should have provided. If any of the elements appear to have dropped from the starting levels, then they are being taken up by the plants faster than they are replaced by the stock solutions, so increase this element in the original formulation. Decrease other elements if required. Carry out this analysis process throughout the crop’s lifecycle to determine formulation changes that need to be made at each stage of growth, and apply these to later crops.

7. The process of formulation adjustment can be complex as many of the fertiliser salts don’t just supply one element. Calcium nitrate, for example, supplies both nitrate and calcium and thus if nitrate needs to be increased and calcium decreased, then other salts need to be used to achieve this. To simplify this otherwise quite complex process, nutrient formulation software have been developed which can carry this out automatically giving the required ppm of each element without the calculations involved.

8. Regular solution analysis will also indicate when the solution is becoming so out of balance that a complete replacement (i.e. dump and replace with fresh solution in recirculating systems) is required. It will also show if levels of unwanted elements such as sodium are

accumulating and whether dumping is required for this reason.

How well a nutrient formulation performs in any given hydroponic system depends on plant nutrient uptake, the suitability and balance of the formulation chosen and the accuracy of weighing up the fertiliser salts and subsequent dilution for use. Most commercial growers carry out the process of regular nutrient solution analysis either on site with their own equipment or by sending solution samples to an agricultural lab. Portable, onsite nutrient analysis systems which measure individual elements are used by many large scale hydroponic producers as they have the advantage of giving instant readings. The Hanna Nutrient Analysis Photometer instrument is one such tool allowing NO_3, NH_4, P, K, Ca, Mg and S in the nutrient solution to be measured directly by the grower. Smaller growers may not be able to justify the use of solution analysis on a regular basis, however keeping check on growth rates and yields, any signs or symptoms of a nutrient deficiency or toxicity, and even comparing plants grown with different nutrient products or formulations can all help in the process of optimising plant nutrition.

Suggestions for Beginners

For beginners who may still be unsure about the type and quantity of nutrients to use, some relatively simple techniques can help you get started:

1. Consult tables - the most suitable ranges of nutrient concentrations for nutrient solutions appear in the table presented earlier.

2. Experimentation – try growing a few plants of the crop you are interested in. If these show recognisable signs of nutrient deficiency or toxicity then you can adjust your nutrient solution accordingly and ensure the pH is right.

3. Test the nutrient status of the run-off solution to determine which nutrients are being taken up by the plants and in what quantities, and adjust the nutrient solution accordingly.

4. Get a rough indication of nutrient requirements by consideration of the type of crop you are growing e.g. high nitrogen for leafy crops.

5. Check agricultural and horticultural journals and texts for nutrient advice and research results on particular crop species. A good example is the text *Plant Analysis* edited by DJ Reuter and JB Robinson (Inkata Press, Melbourne), which gives advice on nutrient requirements for a wide range of crop plants based on analysis of the relationship between yields and nutrient concentrations in plant tissues.

6. Use software programmes (such as the ‘Nutron 2000+ Edition 3’ hydroponic nutrient formulation software) which will not only provide accurate starting formulae for most commonly grown crops, but also allow a grower to create a new formula and adjust this for season, stage of growth, water supply, etc. Inexperienced growers can manage and formulate nutrients without having to do the calculations themselves.

CHAPTER 6 ORGANIC HYDROPONIC NUTRIENTS

Organic nutrient solutions and sources for soilless cropping are a relatively new concept in hydroponic production and one which is somewhat controversial.

Worms feeding on organic materials in this bathtub produce nutrient rich solutions that will be collected from below the plug hole when washed through. Obtaining an organic nutrient rich solution is the easy part. The way in which it is used for anything like serious hydroponics may require insight, innovation, knowledge and experience

Brief History

In the past, hydroponic nutrition has been completely based on the use of chemical fertiliser salts which do not contribute organic, carbon-based compounds to the nutrient solution. While some of the commonly used hydroponic fertilisers such as magnesium sulphate are naturally mined minerals and allowable under organic production, many of the others used in standard nutrient formulations such as calcium nitrate, monopotassium phosphate and iron chelate, are considered to be manmade or synthetic and hence are not permitted under organic production.

Issues with Organics

The first issue with using organic materials as nutrient sources in hydroponic systems is that these types of materials are often low in nutrients and have unknown nutrient concentrations. They also require microbial action to convert organic compounds into plant usable nutrients and thus result in a high biological oxygen demand which can suffocate root systems through a lack of dissolved oxygen.

The second issue is that while many hydroponic growers would like to take advantage of the rapidly expanding and often highly profitable markets for organically certified produce, soilless systems in many countries are not considered to be ‘organic’. To sell produce as ‘organically certified’ a grower must follow strict guidelines set out by one the many organic certification agencies, be regularly audited and comply with a number of standards. Organic certification agencies exist in most countries, however they differ considerably in their standards and definition of what is considered to be ‘organic’ production. In most parts of the world, officially certified organic systems must have soil as the ‘cornerstone’ of production, however in the United States certain types of hydroponic systems are considered to be organic and can become organically certified without the use of soil. While this definition of whether hydroponics is organic or not is still under debate, home gardeners need not bother with the large scale logic, but rather decide what organics means to them and follow techniques that fulfil their own personal ideology. In many countries the use of aquaponic systems where fish farming waste is used to grow soilless crops may be considered for organic certification, provided certain conditions such as not using chemical pesticides or additional synthetic fertilisers are met.

Types of Organic Systems

There are three main types of organic hydroponic systems: NFT or solution culture, drip irrigated substrate culture. and aquaponics. Organic NFT or other solution culture systems such as pond/ raft/float or raceway systems exist in the United States as commercial organically certified operations and these are the most technically challenging to run. Many of these growers utilise hi-tech, newer organic nutrient concentrate bottled products which are OMRI (Organic Materials Review Institute) certified for use in organic systems. Solution culture systems still rely on microbial action to break down organic compounds and release nutrient ions for plant uptake, and commercial microbial inoculants products are often added to the nutrient solution to help with this process. Most other countries do not consider solution culture to be an acceptable organic method for crop production due to the absence of soil or a natural growth substrate.

Drip irrigation substrate culture for soilless cropping typically incorporates the use of a 'natural' medium to support the plants and microbes which carry out nutrient conversion. The substrate gives a good degree of 'buffering' capacity to the system and provides a more ideal environment for the nutrient conversion microbes which form the basis of the system. In the United States, organically allowable growing substrates are listed by OMRI, however many growers have found coconut fibre to be ideal and it is one many hydroponic producers are already familiar with. Coconut fibre for use in organic production cannot have had any synthetic materials added to it, including 'conditioning' fertilisers or surfactants and there is a list of OMRI certified coco products provided. Some brands of peat, perlite, composts and vermiculite are also listed as OMRI certified with allows for flexibility with blending growing substrates and using these as propagation materials. Many commercial organic growers blend coconut fibre with other materials such as composts or vermicast (worm castings) as these materials not only provide a small amount of readily available nutrients, but also a wide range of microbial species which can immediately start the nutrient conversion process when fed organic nutrient solutions.

One of the most successful systems for organic hydroponics has to be aquaponics. If these systems are well run with the correct fish to plant ratio, and a good rate of mineralisation carried out by specific bacteria, aquaponics is one of the easier approaches to organics. Newer growers should start with low nutrient-demanding crops such as lettuce, salad greens and fresh herbs and gradually build up to fruiting plants as the system matures and higher rates of mineralisation occur. Even though aquaponics supplies good levels of nutrient ions from fish waste, high nutrient-demanding crops may still need supplementation and, in particular, extra trace elements from time to time to keep yields and fruit quality high. Aquaponic systems may use either solution culture or substrate culture such as large gravel beds through which the nutrient-rich fish waste water flows to provide organic nutrition for plant growth. The microbial conversion of the organic fish waste, which is high in nitrogen, is carried out by microbial populations which colonise surfaces in the system and with the use of specific bio-filters.

Allowable Nutrient Sources and Products for Organic Production

While hydroponic systems are not technically considered organic in many countries, they are legally allowable in the United States and, in fact, many production and high yielding organic greenhouses are currently in operation. To use this is an example of how organic nutrients are sourced gives an indication of how these hydroponic systems operate effectively where certification is allowable. The United States Department of Agriculture (USDA) national organic program sets the standards for what is permissible in an organic system and provides lists of allowable inputs.

For hydroponic growers, often the easiest way of finding out what they can and cannot use in an organic hydroponic system is to check the OMRI website where they will find a list of the allowable products (fertilisers, growing mediums, pest and disease control products, etc.) for organic production. There are hydroponic products which are approved by OMRI as organically acceptable which display this on the product label or advertising. There are also other products which are OMRI listed but not specifically designed for hydroponics, although they can be incorporated into a soilless system anyway. Most commercial organic hydroponic growers use an OMRI listed liquid fertiliser blend and there are many of these to choose from. Large scale growers often need to blend 2 or more of these to get the balance of nutrients just right for the crop they are growing.

On top of this, the liquid fertiliser products may need some amendment and organic production does allow for the use of some fertiliser salts, so organic hydroponic plants are not totally reliant on organic compounds. These allowable fertilisers have to be ‘naturally occurring’ and the OMRI lists contain a good range of these which can be used to boost the mineral content of organic nutrient solutions. Some of the allowable fertiliser salts are: boron (borax and solubor), calcium carbonate, copper sulphate, dolomite, iron sulphate, magnesium sulphate, manganese sulphate, potassium sulphate (non synthetic) and potassium chloride. Fertilisers which are considered ‘synthetic’ such as calcium nitrate, potassium nitrate and monopotassium phosphate which make up much of the volume of standard hydroponic nutrient formulae are not allowable. Nutrient additives and boosters for organic production are wide and varied, however humic and fulvic acids are organically allowable and are well known beneficial supplements for hydroponics.

Making Organic Nutrient Solutions Onsite

Although many organic hydroponic growers on both a small and large commercial scale make use of premixed bottled concentrates, it is possible to make organic nutrient solutions onsite completely from raw materials rather than relying on commercial products. While liquid bio-digesters that turn raw organic materials into usable plant nutrients have been used with success by some growers, for smaller systems the more reliable method is vermiculture, or worm farming. Vermiculture is a very efficient way of processing high mineral raw materials such as manures, limestone, blood and bone, fish meal, seaweed meal, guano, and others into a usable, mineralised hydroponic nutrient solution that also has the benefit of diverse populations of beneficial microbes.

The success of using the vermiculture system to process organic fertilisers relies on two things:

1) The vermicast must be processed to completion then extracted into water for use in a hydroponics system. The extract or liquid draining from the vermicast system should not be used as a nutrient solution until the vermicast itself has been fully processed i.e. it is a rich, dark vermicast with no sign of raw material left (many 'worm juices' on the market are highly diluted and often not balanced enough to use as a standalone nutrient solution).

2) Secondly, the quality of the raw materials going into the vermicast system will determine how balanced the final nutrient will be. High mineral sources are often dried and ground products such as fish meal, blood and bone etc, while food scraps, weeds and vegetation contain only very low levels of minerals and will not make a nutrient solution that is concentrated enough for most hydroponic systems.

Microbial inoculants and organic nutrients

A high quality substrate forms the basis of many organic systems, and to make sure it is going to perform well with organic nutrients it can also be inoculated with one of the many microbial products which are organically allowable. This inoculation process is beneficial if continued throughout the plant's life. Beneficial microbe products for addition to the nutrient solution or drenched into the root zone have become common additives in hydroponics anyway, but they are even more essential when using organic solutions. New organic substrates incorporated into a hydroponic system should be 'conditioned' before use. That is, they need to be fully moistened, inoculated with microbes, fed a small amount of organic nutrient, and left to sit in a warm growing area for at least a week or two before planting out. This just gives the microbial communities time to establish and build up numbers before starting to break down organic compounds into plant usable nutrient ions ready for the first plants to go in.

EC and pH Control in Organic Hydroponics

EC and pH control in hydroponics is different in organic systems than in traditional fertiliser based systems. Many organic nutrients don't conduct electricity hence readings of EC may not be a true indication of the concentration of an organic solution. Also, pH levels tend to run higher in healthy organic systems than many growers are used to maintaining in standard hydroponics. Since pH lowering acids commonly used in hydroponics such as nitric and phosphoric are not organic, pH is best left to stabilise on its own. Some organic nutrient products naturally have a very high pH, so growers should try to select those which have a more suitable pH range for use in soilless systems

Problems with Organic Nutrients

To replace highly effective and carefully calculated fertiliser salts with organic nutrient sources is not an easy process. Manufacturers of hydroponic fertiliser products and commercial growers making up their own formulations go to great lengths to get the ideal ppm of each nutrient ion in their products so that plants will grow as fast and balanced as possible. With organic nutrient sources it's not possible to be so precise, so mineral deficiencies within organic hydroponic systems are a very common problem.

The main issues with nutrition in many organic hydroponic systems involve the supply of nitrogen, calcium or iron. Nitrogen is made available through the microbial conversion of organic compounds into nitrate for plant uptake. If this conversion process is slowed or does not match plant requirements, nitrogen deficiencies rapidly develop. The bacteria which convert organic compounds to plant available nitrogen forms require specific conditions for optimum rates of mineralisation, and low temperatures in particular can slow this process.

Calcium is another element which can be limiting in organic solution as plants require large amounts of calcium and organic systems cannot use calcium nitrate fertiliser. Some organic growers may obtain a certain amount of calcium from their water supply where this occurs naturally and this can be of considerable benefit in their systems. Other organic calcium sources such as limestone tend to be slow-release and hence must be planned ahead to allow suitable levels of calcium nutrition for the crop.

Iron deficiency is another common problem in organic hydroponic systems as iron chelates, which are stable at a wide range of pH values, cannot be used under organic production standards. Iron sulphate is an allowable input into organic hydroponic systems, however this is not stable under soilless production and tends to form iron hydroxides which are insoluble. Where additional iron is required in an organic nutrient solution, an organic chelate complex can be made by mixing iron sulphate with citric acid which is a natural chelation agent.

Just as mineral deficiencies are common with organic hydroponics nutrients, toxicities are also more of an issue than with traditional, fertiliser based hydroponic solutions. Organic materials contain not only plant usable nutrients, but also other elements which may create problems with plant growth. Many organic nutrient sources are naturally high in sodium which can accumulate to high levels in recirculating systems. While some crops such as tomatoes are fairly tolerant of high sodium levels, other such as lettuce are not and sodium levels may need to be monitored. High levels of certain trace elements may also occur in some organic nutrient sources and in the past there has been concern regarding levels of heavy metals, such as mercury, which may be present in fish-based nutrient concentrates. Growers should always check the full elemental analysis of any commercial organic nutrient product and obtain a lab analysis of the diluted solution if this is not available to check for levels of plant usable and non usable elements.

One of the other main problems with organic nutrients is concentration. Most liquid products are not as concentrated as standard fertiliser salt-based formulations hence growth can become weak, stretched and more prone to disease. Growers need to be aware of what underfed plants look like and boost nutrient concentration as soon as this condition is seen. Nutrient additives and boosters such as humic and fulvic acid are a good addition for organic systems as they help facilitate nutrient uptake and are generally considered to be organic.

Organic nutrients also come with a great deal of carbon which normal non organic nutrient products don't provide. This carbon is an ideal source of food for microbes in the nutrient solution and root zone where it feeds both beneficial and pathogenic fungi and bacteria. If unwanted microbes escalate out of control by feeding on the carbon from organic nutrient sources, then conditions can become toxic, creating slimy nutrient solutions, anaerobic root conditions, diseases and even plant dieback. To avoid all these problems, those starting out experimenting with organic hydroponics should begin slowly with systems that are known to have a better success rate with these types of nutrient sources.

Another important aspect of controlling microbial growth in the nutrient solution and root zone is control over the irrigation system. With organic systems the irrigation system needs to be run a little differently than traditional non organic hydroponics. Drip irrigation is advised since the root zone should never be over-saturated with only a small volume of leachate from the base of the growing containers required. The root zone in organic systems is finely balanced between the requirements of the nutrient conversion microbes and the root system itself. Both require high levels of oxygenation and over-watering excludes much of the aeration in the pores of the growing medium. Organic systems have a higher requirement for oxygenation in the root zone due to the heavy populations of microbes which are required, hence many failures with organic crops are directly attributable to over-watering and/or poor aeration.

CHAPTER 7 TISSUE CULTURE NUTRIENTS

Plant tissue culture, like hydroponics, involves growing plants without soil. Unlike hydroponics, tissue culture involves growing very small pieces of plant tissue rather than complete plants.

Hydroponics vs. Tissue Culture

A hydroponic grown plant will have buds, stems, roots and leaves, and perhaps other parts such as fruits or flowers, whereas a tissue cultured plant may start out as just one type of tissue (e.g. a section of bud without a complete stem).

Plant tissue culture is a propagation technique that involves growing new plants from tiny pieces of sterilised plant tissue, commonly on the surface of an agar-based growth medium to give an aggregation of undifferentiated plant cells. Once the mass becomes large enough, hormones can be added to the growth to cause the cells to change into roots, stems and foliage. Because tissue culture deals with undifferentiated tissue, it is more complex to grow a plant this way than it is to grow a plant in hydroponics.

Since tissue culture deals with such tiny pieces of tissue, the plants are more vulnerable to disease and adverse environmental conditions than in hydroponics. However, since both are forms of growing without soil, knowledge and understanding of one can inform us, to some degree, on how to manage nutrition in the other. The nutrition normally supplied by soil needs to be supplied to the plant in tissue culture, just as it does in hydroponics.

NFT - Excess nutrient solution collects in containter then is recycled through the system

Tissue culture is different to hydroponics in a number of ways:

- Tissue culture deals with very small pieces tissue from just one part of a plant (e.g. the tip of a shoot) whereas hydroponics is growing the entire plant.
- Because pieces of tissue culture plants are tiny, they are more susceptible to disease; hence conditions need to be much more sterile than for hydroponics.
- Because the cells in tissue culture are physiologically just one type, chemical hormones need to be used in tissue culture to manipulate the development of different types of cells as the plant grows (a tissue culture plant may start as a cluster of undifferentiated cells; but a hydroponic plant starts as a large quantity of root cells, plus lots of stem cells, leaf cells, and perhaps even flower and fruit cells).

Nutrient Supply in Tissue Culture

In tissue culture plants need the same macro, micro and trace elements that are required by all plants. The other requirements include an appropriate growing culture often referred to as a support matrix e.g. agar, agar rose or gellan gums plus vitamins and a source of carbon that plants grown in the soil and in hydroponics gain through photosynthesis. A range of additives other than nutrients must also be supplied. These include hormones which are growth regulators required to stimulate cell division or differentiation, and reagents which restrict certain types of growth. These are discussed in later notes.

Definitions

mmol/L: millimoles per litre is often abbreviated as mM. It is the measure of mass concentration used in tissue culture for nutrients and reagents. In the United States and some European countries the measurement of mass concentration is in mg/dL (milligrams per decilitre).

µM: micron or micrometre is used as a measure of trace elements in tissue culture.

Concentration of nutrients commonly found in tissue culture nutrient solutions

Calcium (Ca) as calcium chloride or calcium nitrate: 1-3mM

Magnesium sulphate (Mg) 1-3mM

Nitrogen (N) as NO_3^- oxidised and NH_4^+ reduced: 25-40mM and ammonium at 2–20mM

Phosphorus (P) as phosphate (PO_4^- or potassium hydrogen phosphate): 1-3mM

Potassium (K): 20-30mM

Sulphur (S) as SO_4^2 using magnesium as the cation: 1-3mM

Iron (Fe): supplied at 0.1µM

Boron: supplied at 25–100µM

Cobalt: supplied at 0.1µM

Molybdenum: supplied at 0.1µM

Zinc: supplied at 5-30µM

Manganese: supplied at 20-90µM

A Tissue Culture Medium

Most commercial tissue culture media are complex mixes of perhaps 60 or more different components, all calculated in precise proportions. However, it is possible to do tissue culture with a much simpler mix, although a simpler mix will not provide as good or as reliable results.

In 1986, M. Bridgen proposed the following simple mix for someone to use when starting out in tissue culturing:

First:

Create a fertiliser solution with a ¼ teaspoon of an all purpose soluble fertiliser (NPK 10:10:10) dissolved in 1 gallon of water.

Next mix the following:

½ cup of the above nutrient solution

⅛ cup of sugar (refined white table sugar)

1 cup of tap water

½ a (250mg) Inositol tablet (a carbocyclic sugar-based health supplement)

¼ vitamin tablet with thiamine

2 teaspoons of agar flakes (often available from health food stores)

These ingredients are then boiled while stirring until the agar has melted. It is then poured into small sterile glass containers.

These are placed in a pressure cooker at 15 pounds pressure for 15 minutes to sterilise before use. Bridgen successfully propagated *Nephrolepis* fern rhizome tips and *Saintpaulia* leaf and petiole sections with this medium.

Other Additives in Tissue Culture and Hydroponics

- Sugars (tissue culture)
- Myo-inositol or sugar alcohol (tissue culture)
- Carbon and energy sources (tissue culture)
- Inoculants (hydroponics and tissue culture)
- Vitamins (tissue culture)
- Hormones (hydroponics and tissue culture)
- Root stimulators (hydroponics and tissue culture)
- Enzymes (hydroponics and tissue culture)
- Amino acids (hydroponics and tissue culture)
- Undefined organic supplements e.g. protein hydrolysates, coconut milk, yeast extract, fruit pulp, fruit juices, etc. (tissue culture)

- Foliar spays (hydroponics and tissue culture)
- Leaf boosters (hydroponics)
- Flower stimulators (hydroponics)
- Pesticides (hydroponics)

Organic Compounds

Organic compounds are added in large quantities to culture media.

Sugars

Sugars serve as an energy source for plant culture. Sucrose is the most commonly used sugar in plant culture media, although glucose, fructose and sorbitol are also used in some medium formulas. Sucrose is partially broken down into fructose and glucose during autoclaving (sterilisation). Sucrose also acts as an osmoticum in the medium i.e. it helps to increase or maintain osmotic pressure. Generally, 20-40 grams of sucrose is added in each litre of liquid medium. Starches are also used in some medium formulas both as the support substance and energy source.

Vitamins

Vitamins can improve plant growth in culture but are not absolutely necessary for growth. Of all vitamins, only thiamine (B1) is considered to be essential for many plant species in culture. It is required for carbohydrate metabolism and the biosynthesis of some amino acids. Nicotinic acid (niacin) and pyridoxine (B6), biotin, folic acid, ascorbic acid (vitamin C) and tocopherol (vitamin E) are also used in some media.

Myo-inositol

Myo-inositol is a sugar alcohol and is thought to be important in membrane and cell wall development. It is usually added to media for monocotyledon plants as well as some dicotyledons and gymnosperms.

Complex organic compounds

Complex organic compounds such as coconut milk or juice, yeast extract, fruit juices and fruit pulps are used in some medium formulas. It is not known exactly what components in these organic supplements are responsible for the improved growth of the culture.

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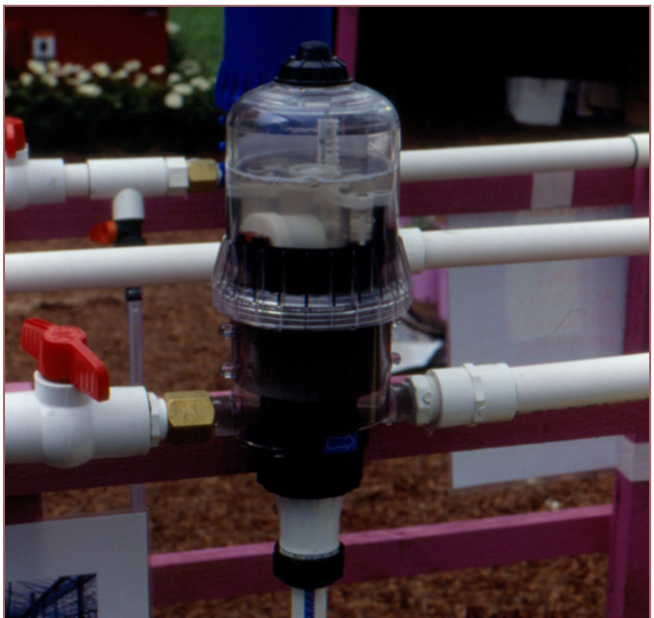
CHAPTER 8 MANAGING CONTAMINANTS

The management of contaminants is largely concerned with assessing the quality of the water supply and monitoring nutrient solutions to address threats to the growing environment.

Water Quality

Hydroponics is reliant on a pathogen and contaminant-free water supply in order to produce healthy plants and prevent blockages in the system. Unfortunately, no water supply is totally pure and especially water sourced from dams and streams. That's why filters, filtration systems, aeration or chemicals are used to ensure that the water is of a standard needed for healthy plant growth. There are many ways to disinfect or purify water including the use of chemicals, gels, filtration, UV rays, ozone and chlorination (the last of which needs further treatment to remove the chlorine before use). Disinfection is also important when reusing nutrient solutions in a recirculating system.



Fertigation injectorscan

Insoluble contaminants in the water supply

The water supply in hydroponics must be free of insoluble contaminants in order to prevent any blockages within the system. Water that has not been filtered or treated in some way, especially water from sources other than tap water, is never pure or free of insoluble solids i.e. colloids. Iron in the water supply is common and it is considered an insoluble contaminant because in water iron oxidises to rust fairly rapidly. Iron can be removed from a hydroponics system through aeration. This causes the iron to settle on the bottom of the tank from where it can be removed. Alternatively, it can be removed through filtration. There are several ways to remove contaminants but commonly coagulants such as alum or polyelectrolyte gels are used. These are settled into settling tank and removed with a sand filter.

Chlorine and chloramine in the water supply

Tap water also has its drawbacks. In particular, chlorine is added as a disinfectant and although chlorine is needed by plants it is only needed in very tiny amounts. If chlorine is added to a nutrient solution and tap water is used to mix it, this may cause an overload and result in toxicity to the plants. Chlorine also kills microorganisms which live around the root zone and are important to organic nutrient supply. This is an important consideration if you are using inoculants. Chlorine does evaporate from water when boiled however a chlorine filter is recommended.

Chloramine is a chemical compound of chlorine and ammonia. It is also used in public water systems as a disinfectant. Unlike chlorine, chloramine does not evaporate even when boiled, and needs a specific filter; combined filters that remove both chloramine and chlorine are readily available. Chloramine inhibits the growth of plants and can cause browning of the leaves, especially apparent in lettuces.

Dissolved ions in the water supply

Dissolved ions are another problem associated with water use in hydroponics due to their impact on nutrient supply. The nutrient ions, which occur naturally in unfiltered water, have to be taken into account when adding further nutrients to create a fertiliser solution. Water that is considered 'hard', i.e. water which contains calcium bicarbonate and magnesium bicarbonate, is not usually a problem to use after the bicarbonate has been neutralised with an acid if it is too high. However, if the concentration of nutrients in water is high and it is not taken into consideration when formulating nutrient solutions, it will impact on plant health.

Sulphur and iron in the water supply (along with salts - discussed later) also have a negative impact on microbes living within the roots zones of plants. This needs to be considered if you are using inoculants.

Pathogens in the water supply

Like insoluble contaminants, pathogens are another problem in an unfiltered or disinfected water supply. This is not a problem in tap water but, as described above, if you use tap water you do need to remove other contaminants. If using another source of water supply, the risk of pathogens is higher as is the risk associated with introduction of pathogens into a recirculating system.

Sodium chloride in the water supply

Sodium chloride, which is what we commonly use as table salt, can be problematic in the water supply. High levels or sodium chloride are found in water supplies in some countries. When concentrations are higher than the needs of the plant, or higher than what the plant can uptake, sodium chloride can build-up in the hydroponics system to levels which can cause the death of plants. Even though, as discussed in previous notes, both chloride and sodium are micronutrients and essential to plant growth, it is only needed in minute amounts and even small increases are detrimental to plant growth and health.

Salinity build-up

Besides naturally occurring sodium chloride, nutrient solutions provide salts to plants. When a plant uses a nutrient from a chemical 'salt' molecule supplied in a nutrient solution it is, in fact, using only one part of that molecule. The remaining part of the molecule generally stays in the hydroponic system. It may be used by the plant, but more commonly it builds up in the system and eventually can reach a level of concentration where it causes damage to the plant.

This is referred to as 'salt build-up' or a 'salinity' problem. Salinity problems are most common when media with a high cation exchange capacity are used, or in a closed system using the same nutrient solution for an extended period. Salinity problems will sometimes be visible. For example, if you notice a white caking around pipes, water outlets, or on the surface of the media this indicates the problem is reaching a dangerous level.

Salinity can be cured or prevented simply by leaching the salt build-up out of the system by washing it through with water. This water must, of course, be drained out of the system to remove the unwanted salts completely.

Algae

Algae occur naturally wherever you have nutrient-rich water in a situation exposed to light. Although it is usually green in colour it can also be observed as brown, reddish brown or black. Algae can be problematic in hydroponic systems where it may inhabit the channels, pipes, pumps, drippers and emitters and spread into the media. It can, in effect, smother the whole system and seal it off like a carpet. Algae do the following:

- Use up nutrients that should be available for plant use.
- When they die and decompose they use up dissolved oxygen which is needed by plant roots.
- Release toxins during and upon decomposition.
- Attract parasitic insects e.g. gnats and root nematodes.
- Provide a food source for gnat and other insect larvae.
- Attract fungal pathogens by providing them with a food source e.g. Pythium which can then colonise the system.

Without light algae cannot grow. Although it is almost impossible to exclude all light from a hydroponics system, by covering channels and any other part of the system which carries nutrients and is exposed to light you can reduce the problem. The most common method used is to add light proof covers and plastic film or a dry layer of substrate to the growing beds. If the problem is extensive then it is best to dismantle the system, clean it thoroughly, and start again using the cover suggestions above.

Other approaches for algae control include:

- **The use of algaecides:** although sometimes used in hydroponics, it is not recommended; algaecides can damage plant roots systems along with killing the algae. Algae also regrow very rapidly after treatment.

- **Diluted hydrogen peroxide:** this is sometimes used but is not without problems. It can only be used on older plants with care and at the correct dosage because young plants are too susceptible to root damage.

- **Natural control methods**: grapefruit seed extract is one such method that has proven effective without harming plants.

- **Straw mats:** another method is to place a barley straw mat at the bottom of the reservoir which retards algal growth without harming plants.

Prevention is always better than a cure.

Bacterial contamination

Bacterial infections can cause health problems for the plants grown in the system but can also be transferred from the roots to the leaves and then cause problems for humans upon consumption of the produce. In hydroponics systems, these problems are usually caused by anaerobic bacteria i.e. those which live without oxygen.

Other than disinfected tap water, most water supplies (lakes, stream, dams, etc.) will have bacteria present within the water. Anaerobic bacteria are hard to control and can cause serious problems in hydroponic growing.

Control methods include:

- **Chlorination of the water:** one method of control is to use chlorinated water which is allowed to dissipate before reaching the plants. Hydrogen peroxide in small amounts (as discussed earlier) is another method sometimes used. It is very effective but like chlorination it will need to be dissipated before use. Hydrogen peroxide does have the added benefit of increasing the dissolved oxygen content in the water.

- **Beneficial microorganisms:** introducing beneficial microorganisms which feed on the 'bad' pathogens.

- **Sterilisation:** bacteria caused by iron (simply referred to as 'iron bacteria') are usually removed through the sterilisation of the water, and also the nutrient solution.

Disinfection Systems

Filtration

Slow filtration is simple to use, extremely effective, has a low set-up cost and is relatively easy to maintain. Also, it doesn't use technology but instead uses a combination of sand and rockwool. It is a method commonly used by some commercial growers (especially tomato growers). Filtration involves the use of fine sand (graded to 0.2-2mm) that is twice washed and has a pH lower than 4. Water moves very slowly through the several layers at a rate less than 10-30cm per hour which is sufficient to remove most pathogens.

Membrane filtration, sometimes referred to as ultra-filtration, is a commonly used method in many horticultural concerns that only have access to poor quality water. This method uses micro-filters to remove all contaminants and suspended solids as well as bacteria. It is not a suitable method for disinfection of recirculating systems because it also removes nutrients. The filters also tend to clog up readily.

The inclusion of reverse osmosis filters, also sometimes referred to in hydroponics as hyper-filtration, is one of the most common methods of filtration used in hydroponics to filter water prior to use in the system. However, it is a costly and energy-intensive process that also removes all nutrients from the water along with contaminants. There are many different types and brands of RO filters available.

Heat

Heat is another very widely used method of disinfection used in recirculating systems. It is a simple solution which can be incorporated into systems and is very effective against a range of pathogens. Although it has low maintenance requirements it can be expensive to run. The recirculated nutrient solution is initially passed through a 50-70 micron filter and its pH is reduced to 4.5. The filtered water is then run through a first and subsequently a second heat exchanger (with the water being caught into a holding tank in between the two phases); phase one preheats the water and phase two heats the water to the desired temperature (with the use of an outside gas boiler) and keeps it at the temperature for at least 30 seconds. The water is then returned to the first heat exchanger, cooled and then stored, analysed and nutrients adjusted before reuse.

Ultraviolet radiation

Ultraviolet radiation (UVR) is a chemical free, non-toxic method of disinfection that kills all known pathogens. It is a simple system because it doesn't require heaters and is very easy to maintain. There are no alterations in pH or fluctuations in temperature. UV systems usually include a filtration, pump and the UV disinfection unit. UV treatment does have a drawback in that it breaks down chelates in the solution. Some growers suggest it also precipitates manganese. This makes UV treatment most useful as a pre-treatment of water before it enters the system, especially for backyard growers who may not be constantly checking their nutrient status.

Of the three types of UV ray wavelengths, UV-C is the one used in disinfection since its 254 nanometre wavelength has the capacity to destroy most pathogens. In UVR the water is passed through a radiation chamber holding one or more high power UV lamps within a quartz tube. It is a totally computer-controlled system that monitors the UV dosage rate to ensure that the process is effective. A rate of 80 millijoules per cubic metre destroys all pathogens and a higher rate of 250 millijoules per cubic metre achieves complete disinfection.

Ozone

Like UV radiation, ozone also breaks down iron chelates in the nutrient solution. Nevertheless, it is an extremely potent oxidising agent that is commonly used to disinfect water because it quickly destroys most pathogens. Ozone works by 'donating' electrons to other substances. Once this process is complete, ozone converts to oxygen.

In this process, the water is first filtered through a 50-70 micron filter and the pH is lowered to 4-4.5. It is then pumped into a closed holding tank (ozone must not be allowed to escape into the atmosphere) and injected with ozone. It is an effective system of disinfection and sterilisation but is a bit more costly than heat treatment described above.

Preventing Chemical Contaminants from Leaking into the Broader Environment

All growers, whether involved in a backyard operation or a large commercial set-up, have the responsibility to ensure that nutrient waste does not contaminate the broader environment. There are laws covering this is most regions. Closed systems are far less likely to cause problems than open systems as the water and nutrient solutions are not regularly discharged into the broader environment. However, if open systems are designed correctly they can use the nutrient solution which is not recirculated to fertilise other crops such as turf, etc. The main risk is to water resources since nutrients from fertilisers can leach and contaminate local water bodies. If pesticides are used, this poses a further risk. You should make sure you know the local guidelines for disposal of nutrient loaded water from hydroponics systems and also the capacity for pathogen release into the environment, and the potential for contamination of edible crops grown hydroponically.

Capillary Mat

CHAPTER 9 TESTING SOLUTIONS

Hydroponics is only successful if all the components introduced into the system are balanced correctly. In order to achieve this, regular testing is important.

Important Tests in Hydroponics

A number of hydroponics tests may be conducted and amongst the most significant are:

- Water quality
- Nutrient concentration and balance
- The pH of the solution
- The EC of the solution

Water Quality Tests

Source water quality tests are relatively easy to obtain and should be carried out before setting up a hydroponic operation. Since a number of water quality parameters can affect the composition of the nutrient solution and play a role in factors such as pH management, water testing is a vital component of hydroponic testing. A water analysis or report is always the best place to start if water quality issues are suspected. Municipal water suppliers should be able to provide customers with a full water report which includes mineral analysis as well as water treatment chemicals such as chlorine or others. For those using other water supplies such as ground water, well water, river or dam collected water, obtaining a water analysis is relatively easy and all that is required is to send a sample off to an analytical or agricultural testing lab. Water reports, while extremely useful, may not cover all potential problems however they usually give a fairly good indication of where any issues lie with a water supply.

Combined EC and pH meter

Water samples for testing should be collected in a clean, well-rinsed bottle and sent immediately to the lab. Parameters to be analysed vary slightly between labs, however the following are usually included in a basic 'irrigation water test':

- pH, EC, calcium, magnesium, potassium, sodium, ammonium, nitrate, chloride, sulphate, phosphate, iron, manganese, zinc, copper, boron, molybdate, carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), alkalinity ($CaCO_3$)

Most water testing reports supplied by analytical labs will use units of ppm (parts per million), mg/l (milligrams per litre) or mEq (milliequivalents). Some reports may give a guide to the 'desired level' however these are generally not useful for hydroponic growers and refer to the use for potable (drinkable) water or water to be irrigated onto soil grown crops.

Water quality test results and interpretation

Minerals

Interpretation of a water quality test from the lab can be somewhat confusing and may require the assistance of a consultant, depending on the results and how these may affect the nutrient solution and plant growth. The first quality parameter to consider is the mineral levels shown on the water test report. Some naturally occurring minerals commonly found in most water supplies, such as calcium and magnesium and low levels of trace elements such as copper, boron or zinc, are plant usable elements which help reduce fertiliser requirements if present in high enough levels. However, these should be adjusted for in the hydroponic nutrient formulation so that imbalances in nutrient ratios do not occur over time. This is particularly important in recirculating systems.

Hydroponic nutrient formulations made up from the individual fertiliser salts are easily adjusted for the presence of calcium or magnesium in the water supply, and the amount of calcium nitrate or magnesium sulphate is reduced accordingly. This can also be carried out for small amounts of trace elements. However, if trace elements in the water are higher than those required by the crop, then build-up and toxicity may become an issue over time and the water may need treatment to remove these. Premixed nutrient products cannot usually be adjusted for the presence of minerals in the water supply however some manufacturers do produce 'hard water' and 'soft water' nutrient products which can help adjust for some aspects of the water supply.

Other minerals in the water supply which are shown on water test reports include sodium and chloride. Sodium levels in excess of 2,000ppm have been found in some inland well waters in arid regions, although most well water sources don't pose such as extreme problem. Sodium contamination usually occurs from common salt, sodium chloride, which is present to varying degrees in most soils and may also be present from salty sea spray or salt water penetration of wells, or it may be deliberately added during water softening processes. Sodium is not taken up by plants to any large extent, hence as discussed previously it can accumulate in hydroponic systems (more so in recirculating systems) displacing other elements. Some hydroponic crops such as tomatoes are far more tolerant of high levels of sodium than other more sensitive crops such as lettuce, so this should be taken into account when deciding whether or not a saline water source needs treatment. For moderate levels of sodium, growers can opt to avoid recirculating the nutrient, thus preventing sodium or other unwanted elements accumulating over time. In this case, avoiding recirculating systems such as NFT in favour of media-based 'drain to waste' type setups is usually sufficient to avoid excessive sodium build-up. Likewise, chloride may be taken up by plants to a small extent however certain crops such as cucumbers are known to be chlorine sensitive and they will develop toxicity symptoms if levels are allowed to build up in hydroponic nutrient solutions.

Measures of pH and EC

Water reports produced by testing labs also contain the pH and EC of the water supply. The pH measure is useful because when combined with the alkalinity reading it gives an indication of how much acid may be required in the hydroponic system to keep pH levels within range. The EC measurement of the amount of soluble salts in the water supply is not particularly useful because it does not differentiate between salts. As such, the EC reading may be made up of useful plant elements such as calcium and magnesium or unwanted elements such as sodium.

Hard water and high alkalinity

On water analysis reports these are measured as alkalinity ($CaCO_3$) and bicarbonates (HCO_3^-) in units of ppm or mg/l. This is probably the most common water quality issue dealt with by hydroponic growers worldwide, even those on treated city water. Ground water may be 'hard' as can be river, dam and city water supplies, although rain water in unpolluted areas is usually considered low mineral or 'soft'. Municipal water supplies range from very hard to soft, depending on where the individual city water supply is taken from. Hard water has a high mineral content, usually originating from magnesium, calcium carbonate, bicarbonate or calcium sulphate which can cause hard, white lime scale to build up on surfaces and growing equipment.

Hard water may also have a high alkalinity and high pH, meaning that considerably more acid is required to lower the pH in hydroponic systems to ideal levels and maintain it there. A high alkalinity would be considered to be greater than 300 ml/l of calcium carbonate and a low alkalinity less than 100 mg/l of $CaCO_3$. While hard water sources do contain useful minerals (Ca and Mg mostly), they can upset the balance of the nutrient solution and make other ions less available for plant uptake. Larger commercial growers can counter these problems by adjusting their nutrient formulations to take the levels of Calcium and Magnesium into account and by pre-acidifying the hard water before it is used to make up the nutrient solution or to top up reservoirs. Acid used for this purpose is usually either nitric or phosphoric, or a 50/50 mixture of these. The for this is that acids add minerals to the water or nutrient solution and a combination of N and P from these acids can be adjusted for in the nutrient formulation since both are taken up by plants at relatively high levels. This pre-acidification of the water means that less acid is then required in the system to keep the pH down to optimum levels.

Smaller growers also have the option of using a premixed 'hard water' nutrient product. These hard water nutrients are specifically designed to deal with the effect of hard and alkaline water on the system pH and usually incorporate some of the ammonium form of nitrogen (NH_4) to assist with keeping pH down. Hard water formulations also assist in keeping the macronutrients in balance when using a water source that already contains levels of plant usable elements such as calcium and magnesium. Some growers have in the past made the mistake of using household water softener units to deal with the problem of a hard water source. Unfortunately, while these are fine for softening water for drinking and home use, they usually incorporate a process that adds sodium chloride to the water. As highlighted already, sodium is an issue for hydroponic systems and is an unwanted element that has the potential to cause plant damage, so use of these water softeners for hydroponic water supplies should be avoided.

Organic material and pathogens in water supplies

General purpose water quality tests from the lab tend to measure only minerals, pH and EC of the water supply and not other potential issues such as organic loading, and plant or human pathogens which also affect hydroponic production.

Separate lab testing can be carried out on water supplies to determine the presence of certain pathogens where these are suspected to be an issue. Generally, city water supplies are filtered to remove any organic matter and treated to kill any microbial life which would include human and plant pathogens. However, other water sources including well water, river, dam, and rain water can harbour both organic matter and potentially damaging plant pathogen spores. In reality, many large commercial hydroponic operations use untreated water sources with few problems however in some areas pathogen contamination can be an issue. Zoosporic pathogenic fungi such as pythium and bacteria can survive and be distributed in water. However, these can be relatively easily cleaned up by the grower before use. The safest options are UV, ozone and slow sand filtration as these won't leave chemical residues which may harm young, sensitive root systems. Small UV treatment and filtration systems such as those used in fish ponds and aquariums are suitable for treating water for hydroponic use and will kill plant pathogens and algae. However, these are best used for treating water only, not nutrient solutions as UV can make some nutrients unavailable for plant uptake.

While it is possible to treat water sources with chemicals such as bleach (chlorine) or hydrogen peroxide (H_2O_2), this can be a risky process. Levels of these sanitiser chemicals high enough to kill plant pathogens will certainly damage young or sensitive plants unless they are deactivated or removed before being used to make up a hydroponic nutrient solution. H_2O_2 is deactivated when it reacts with organic matter in the water and chlorine will dissipate over time, particularly if the water is aerated, however determining when these active chemicals have reached levels low enough to be safe for plants is difficult. There are test strips, often sold through aquarium suppliers which may help, but it's often an easier option to rely on safer methods of water treatment for pathogen control.

Nutrient Balance Testing: Solution Analysis

How well a nutrient formulation performs in any given hydroponic systems depends on plant nutrient uptake, the suitability and balance of the formulation chosen, and the accuracy of weighing up the fertilizer salts and subsequent dilution for use. Most commercial growers carry out a process of regular nutrient solution analysis either on site with their own equipment or by sending solution samples to an agricultural lab. This analysis shows levels of each element in ppm, which can be compared back to the values provided in the original formulation. Any differences can be adjusted for so that the formulation often changes over time as required.

To collect samples of nutrient solution for lab analysis is relatively simple, but must be carried out correctly so that contamination does not occur and so that the sample is representative of the crop. Solution samples from recirculating systems such as NFT are easy to collect and just require a bottle of solution to be taken from the nutrient tank and sent off to the lab as soon as possible. The sample bottle should be clean and rinsed with solution before filling. For hydroponic substrate solutions, collecting a sample of nutrient solution requires a shallow container to be placed under a number of separate growing containers/bags/slabs to collect the nutrient drainage (or leachate) solution which flows from the base of the substrate at each irrigation cycle. This drainage sample or leachate solution is collected from several plants around the system and mixed to give a representative sample before being sent off to the lab. Lab analysis of nutrient samples test for the following parameters:

- pH, EC, NO_3, NH_4, Ca, Mg, P, K, S, Na, Cl, Fe, Mn, B, Cu, Zn, some labs may also test for Mo and Al.

As with water supply, these may be expressed in units of ppm, mg/l, mEq or mmol/l depending on the lab reporting system.

Once the nutrient solution analysis has been returned from the lab, this information can be used to make any adjustments required to the nutrient formulation. This allows adjustment of nutrient ratios, corrections of deficiencies, or allows for reductions in the levels of elements which may have been accumulating over time. Nutrient solution testing can also show up other problems such as the build-up of elements from the water supply (sodium in particular) or from the use of pH correction chemicals. In recirculating systems such as NFT, nutrient testing is a particularly valuable tool as it helps determine how long the solution can be run in the system before it becomes so out of balance that the solution must be replaced.

Plant Testing: Foliar Mineral Levels

Plant or foliar analysis involves taking a small sample of leaves, which is usually the youngest most recently expanded leaf from a number of plants, and sending this sample to an agricultural lab for mineral analysis. Plant analysis labs usually provide information or a kit containing sample bags and details of the sampling process. This includes the number of leaves required and whether these should be washed, refrigerated or subjected to another treatment before sending in for analysis. If plants are particularly dusty, or have been sprayed with any chemicals or other products which may interfere with the results, washing the sample with RO or distilled water followed by complete drying is advisable. Leaf samples can deteriorate quickly so should be immediately sent to the lab.

The plant analysis lab report generated usually states each of the macro elements analysed for in the foliage (N, P, K, Ca, Mg and S) as a percentage of dry matter, while micro elements present in much lower concentrations (Fe, Mn, B, Zn, Cu) are expressed as either ppm, mg/kg or ug/g. Some laboratory reports will also include a guide to the ideal foliar level range of each nutrient for specific crops to compare the results against, however not all do and often interpretation is reliant on the grower. For most commonly grown hydroponic plants there are guidelines provided in plant nutrition books and websites that will indicate what the ideal foliar levels are for different species and at different stages of growth. Foliar mineral levels at which deficiency or toxicity symptoms would be expected to occur are also useful to have on hand when comparing plant analysis reports.

The most common use of foliar analysis is when suspected deficiency or toxicity symptoms are starting to show on plants. Since many physiological, disease and nutritional disorders can look quite similar, often plant analysis is used to rule out or confirm specific nutrient issues so that these can be rectified quickly and correctly. Often foliar analysis is used alongside nutrient solution analysis to determine changes which might be required or supplements that can be provided to help prevent deficiencies from continuing to occur. Another common use of foliar mineral analysis is simply to confirm that nutrition has been optimal and that the nutrient formulation provided to the plants is suitable at the current stage of growth. Growers who are experiencing unexplained symptoms such as an overall lack of plant vigour, plant stunting or low yields may use plant analysis to rule out nutrition as the specific cause of any issues, or to diagnose nutritional problems before they become more severe.

Recommendations for the ideal level of each nutrient in foliar samples vary slightly from one reference source to the next and for this reason ideal levels are simply given as a range within which most healthy plants should fall. This is typically somewhat species dependant. For example, normal foliar levels of nitrogen (N) in lettuce (crisp head) are often stated as being 3 - 4.5%, while in tomato which is a crop requiring a higher level of nutrition, levels of 4.5 – 5.5% may be suggested. Deficient levels for tomatoes would be less than 2% N. For potassium (P), ideal foliar levels are 4.5 – 8 % in lettuce (crisp head) and 4 – 6% in tomato, with deficient levels being below 2%. Micro or trace elements often have a broader range of ‘normal’ levels in healthy plants. In tomato, iron levels should be within the range 80 -

200ppm and manganese 50 – 300ppm, with iron levels become deficient below 60ppm and manganese below 20ppm. By comparing the foliar mineral levels returned on a recent lab analysis to the 'normal healthy' range for the plant species being grown, it is possible to see which nutrients fall outside the recommended range. This can help detect any potential issues before a stage of deficiency has been reached and plant growth becomes affected.

Perhaps one of the most common mistakes made with using foliar analysis data is that while it may show up a mineral deficiency problem, this may not necessarily be directly caused by a lack of that element in the nutrient solution. Other factors also affect plant uptake and nutrient transportation within the plant and subsequent foliar mineral levels. In this case, boosting nutrient solution levels of the element shown to be low or deficient on the plant analysis report will not improve the problem, and other factors need to be addressed. Nutrient interactions can also induce nutrient deficiencies in the foliar analysis tests despite there being no actual lack of a particular element in the nutrient solution. An example of this is the use of high levels of the ammonium form of nitrogen (NH_4) which also restricts calcium uptake in the root zone. This can induce calcium deficiency in the foliage and fruit of the plant which subsequently shows up on the foliar analysis reports. Under certain growing conditions such as suboptimal temperatures, certain plants are unable to take up iron or phosphorus efficiently and may show low foliar levels despite these elements being present in the nutrient solution at good levels. If the plant roots have been suffering from a root rot pathogen or root dieback, foliar mineral analysis may show multiple deficiencies in many nutrients however this is simply due to the root system being unable to take up sufficient minerals from the nutrient solution due to tissue damage. A lack of oxygen in the root zone can also induce mineral deficiencies which show up on foliar analysis reports, but this is also due to damaged roots which are unable to take up the nutrients required for healthy foliar levels.

pH Tests for Hydroponics

The ideal pH range in hydroponics falls between pH 5.8 and 6.2 (and depends on the needs of the crop in question) but should be no higher than pH 6.5 and no lower than pH 5.5. Once the pH falls outside of this range it is important to make adjustments, and there are products specifically designed for hydroponics to adjust pH i.e. to lower pH (increase acidity) or to raise pH (increase alkalinity). It is important to measure pH often to prevent nutrient lock-out, and this should be done daily when you are first setting up the system. There are several ways to test pH in hydroponics:

- **Litmus test strips:** a cheap and convenient way to test pH. The test strip is placed into the water, the colour of the strip changes and is compared to a chart showing the different colour ranges and their corresponding pH. This can be inaccurate as the exact pH may be difficult to ascertain precisely, due to the subtlety of the difference in the colour range.

- **Liquid test:** this is a bit more accurate than the litmus test; a few drops of dye are placed into a small amount of the water from the system – the die changes the colour of the water and again the pH may be determined from a corresponding chart.

- **pH meter:** this is an electronic device which can accurately measure pH. The most expensive of the three methods but also the most reliable. pH meters do need to be calibrated regularly to ensure that they are working accurately and this can be easily done using a calibration solution, but the process does vary from one brand to the next.

EC Testing

EC or the measure of salts in the system is best tested using an EC meter, and combined pH and EC meters are readily available. EC is measured in units of millisiemens per centimetre (mS.cm). EC should be maintained at a level suitable for the crop, stage of development, system and climatic conditions and can be as low as 0.4 for young seedlings and micro greens to over 6.5 in fruiting tomato crops. To lower EC add more water, and to increase EC add more nutrients. Like pH, EC measurement is important to ensure that the plants growing in the system are receiving the correct nutritional balance. Measuring the EC regularly means problems caused by incorrect nutrient balance can be avoided. Remember that an EC reading of zero means that the water is pure.

Automatic EC and pH testing and control

In recirculating systems such as NFT, DFT and float or pond systems, automatic controllers are often used to automatically control and maintain the correct EC and pH level. These units use EC and pH probes permanently installed in the flow of nutrient which measure these parameters at regular intervals. When the controller senses a drop in EC, more stock solutions are automatically dosed into the nutrient flow until a feedback system determines the EC is at the correct level. Water top-ups are also automatically controlled to keep the tank volume consistent. While automatic controllers may seem like the ideal way to reduce time and labour in monitoring the nutrient solution in a system, they don't replace the requirement for manual checks of EC and pH as failures in even well-designed equipment are known to occur occasionally. Automated dosing units installed on recirculating systems are also reliant on correct and regular maintenance as EC and pH probes still require frequent calibration and checking to ensure reliable monitoring and adjustment of the nutrient solution. Furthermore, pH probes in particular have a limited life span and inaccurate readings from these can lead to crop damage and loss.

CHAPTER 10 NUTRITIONAL DISORDERS

Plants require a specific set of nutrients in certain amounts to achieve healthy growth. There is no single correct amount for plants as a whole, since individual types have different requirements and sensitivities.

Nutrition Management

Nutritional disorders fall into two categories: deficiencies and toxicities.

Hydroponics presents the opportunity to manage plant nutrition on a minute level. This makes it possible to maintain ‘optimum nutrient status’ and ensure premium flowering, fruiting, and general health. This micro-management, however, also carries risks: a small error in nutrient calculations can quickly cause adverse effects. This makes a regular diagnostic program essential for plant health.

Magnesium Deficiency

Unlike soils, hydroponic growing methods do not have the ability to inactivate toxic elements and as the water is lost through transpiration, these can therefore end up concentrated in solutions. Some nutrients, in particular trace elements, have a very narrow range between undersupply and oversupply, readily creating the danger of toxicity.

Oxygen and Aeration

Oxygen is required for the process of respiration and while plant leaves have access to more than sufficient O_2, plant roots may become deficient in many growing situations. While hydroponics does offer the opportunity for better oxygenation of the root system than soil based systems, root suffocation due to a lack of O_2 is common in many densely grown hydroponic crops. Oxygen is only slightly soluble in water or nutrient solution with maximum rates of only 12 – 13 ppm of O_2 held at around 10°C, and this can be rapidly taken up by an active root system to the point where suffocation and root cell death starts to occur. The ability of a solution to hold dissolved oxygen decreases as the temperature increases, therefore the importance of solution temperature cannot be underestimated.

Hydroponic growing media need to be porous to allow oxygen penetration and methods should be used to enrich nutrient solutions with as much dissolved oxygen as possible. Dissolved oxygen in a solution (i.e. molecular oxygen found between water molecules) is ‘free’ oxygen (not part of the water molecule) that can be absorbed by roots of plants. It is critical to the health of plants to maintain sufficient dissolved oxygen within the nutrient solution. As suggested above, the most important factor affecting dissolved oxygen is temperature. Salinity is also important but to a lesser degree because its toxic effects on plants (i.e. toxic shock and inability to uptake nutrients) are apparent much faster than salinity impacts on the dissolved oxygen content.

As the dissolved oxygen is utilised by roots it needs to be replaced. The most common methods of aeration are using an air pump and air stone (like in a fish tank) to aerate the solution directly. Hydrogen peroxide (H_2O_2) is another aeration method sometimes suggested (although still somewhat controversial).

Diagnosing Nutritional Stress

The goals of a regular diagnostic program are twofold:

1. Establish a baseline for your crops

2. Catch nutritional stresses quickly, to minimise ill-effects

For large-scale and commercial growers, tissue and leaf-juice analysis allows for identifying specific nutrient concentrations in the plant. These analyses are usually done off-site, at a specialist laboratory. This makes such testing cost-prohibitive in many cases.

There are, however, proxies for the health and effectiveness of a nutrient solution. These are pH monitoring and EC monitoring. Both factors affect the availability of nutrients within the nutrient solution; pH measures medium acidity and EC measures the levels of salts in the solution (refer to earlier notes on EC and EC testing).

Note: be cautious when adding fertiliser. Too little is better than too much, toxic levels can build-up in plants and you can’t take away too much, but you can add more nutrient without compromising the health of the plant.

When starting out in hydroponics try to keep it simple. Use nutrients at half strength during the vegetative growth period and at full-strength during the flowering and fruiting stage. Make sure you regularly empty and refill the nutrient reservoir.

Nutritional Deficiencies

Managing nutritional disorders in soilless culture can be more exacting than traditional growing processes. This is because the plant’s root tips are directly exposed to nutrients; there are no intermediary soil mechanisms. In soil culture, deficiencies are often slow moving. They occur because a plant’s needs, particularly in high-growth periods, exceed the available nutrient content in the soil. This could be because of soil mechanics or general accessibility. This means that in soil culture, there are usually signs before a nutrient crisis hits.

Hydroponics and many soil-free systems supply nutrients directly. When a nutrient runs out, it is because it is all used up – there are no nutrients available. If not caught, identified, and remedied quickly, such deficiencies can cause a shock to the plant, and create rather dramatic changes in plant health and appearance.

Remember too that nutritional deficiency can also be directly related to pH and for optimal nutrient supply a pH of around 5.8 - 6.5 needs to be maintained.

Signs of Deficiency

When one of your crops shows signs of deficiency, it may be tempting to tinker with the nutrient solution immediately. Tinkering without data is always a bad idea; there are many factors to account for in identifying a nutritional deficiency.

Deficiency will vary across plant types i.e. the nitrogen range for one crop will be different to the nitrogen range for another. It is vital to establish baseline requirements for the plants in your system. The type of system must also be considered since a recirculating system is more likely to have confounding factors than a run to waste system.

Diagnosing a plant's nutritional deficiency requires careful analysis of:

- Nutrient content in media
- The plant's symptoms
- Fruit and flower condition, if relevant
- System EC
- System pH
- System temperature
- System aeration

It is important to remember that when a deficient plant is showing clear symptoms, it has already been experiencing deficiency for some time and may take quite a while to show improvement in response to treatment. Note that all plants respond to macro- and micronutrients differently. What is considered deficient in one species may not be deficient in another.

Table: Approximate percentages of macronutrients in leaf tissues considered to be normal, deficient or toxic

Macronutrient	Normal level	Deficiency level	Toxicity level
Nitrogen, N	2.50 - 4.50	<2.50	>6.00
Phosphorus, P	0.20 - 0.75	<0.15	>1.00
Potassium, K	1.50 - 5.50	<1.00	>6.00
Calcium, Ca	1.00 - 4.00	<0.50	>5.00
Magnesium, Mg	0.25 - 1.00	<0.20	>1.50
Sulphur, S	0.25 - 1.00	<0.20	>3.00

Table: Approximate PPM of micronutrients in leaf tissues considered to be normal, deficient or toxic

Micronutrient	Normal level	Deficiency level	Toxicity level
Boron, B	0.10 – 2.00	0.05 – 0.30	0.50 – 2.00
Chlorine, Cl	1.00 – 5.00	<1.00	5.00 – 10.00
Copper, Cu	0.05 – 0.30	0.02 – 0.05	0.20 – 1.00
Iron, Fe	1.00 – 5.00	<0.05	>5.00
Manganese, Mn	0.20 – 3.00	0.15 – 0.25	3.00 – 5.00
Molybdenum, Mo	0.01 – 0.20	0.003 - 0.015	>1.00
Zinc, Zn	0.27 – 1.00	0.10 – 0.20	1.00 – 4.00

Macronutrients: NPK Deficiencies and Toxicities

Nitrogen, phosphorus, and potassium are essential for plant growth and development. They play vital roles in plant physiology. This section discusses how each element contributes to plant growth, then the general mechanical changes caused by deficiency or toxicity, followed by specific concerns for hydroponic growers.

Nitrogen (N)

Nitrogen comprises approximately 2% of the dry weight of most plants. It is an essential and limiting element in plant growth.

In soil culture, a plant can draw up nitrogen appropriately during differing stages of growth. In soilless culture like hydroponics, nitrogen must be supplied in adequate amounts. In the vegetative stage before flowering and fruiting a plant's nitrogen needs are higher, as this is a heavy growth period.

Nitrogen Deficiency

Plants deficient in nitrogen show:

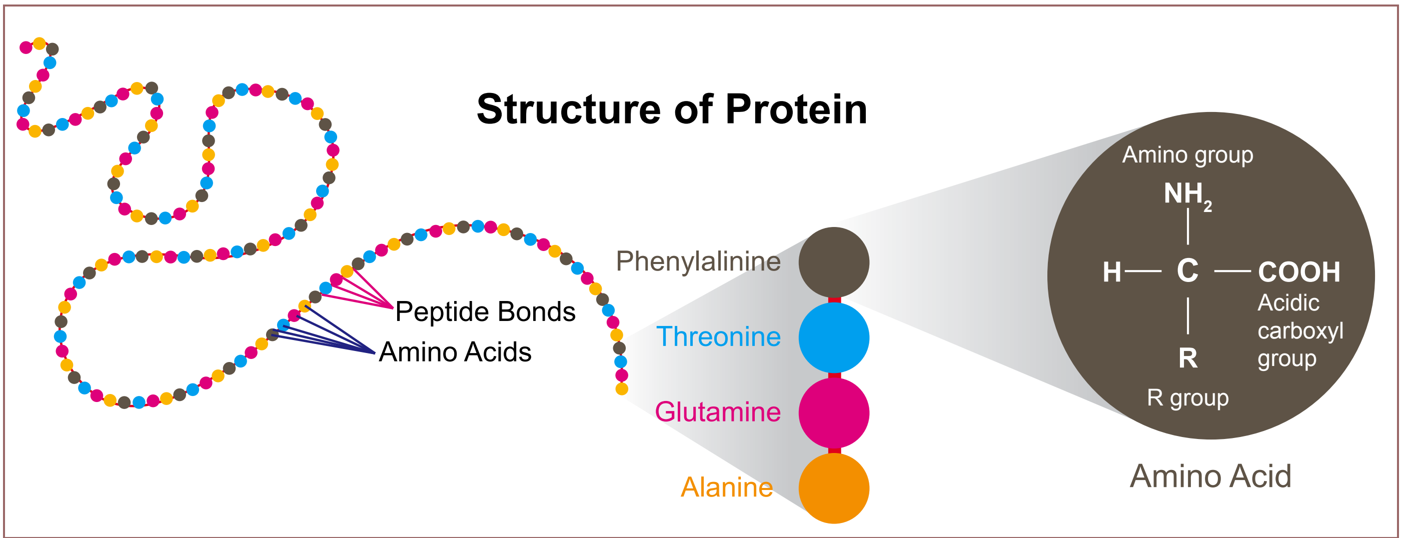
- Restricted growth
- Chlorotic (yellowing) leaves, especially older leaves
- Younger leaves remain green for longer periods
- Corn and tomatoes may show purpling of stems, petioles, and lower leaf surfaces

Nitrogen is essential for creating and maintaining chlorophyll. Chlorophyll gives leaves their green colour, and is necessary for photosynthesis. Photosynthesis is the process through which a plant synthesises food, and thereby energy, for growth. This means that plants lacking in nitrogen will show restricted growth, and yellowing of the leaves.

Nitrogen is a key component in the structure of amino acids. Amino acids are the building blocks for proteins and therefore nitrogen is essential for protein synthesis. Proteins are necessary for cell signalling, to ward off infection, to transport water and nutrients, and more. Without proteins, a plant cannot survive.

Similarly, nitrogen plays an important role in production of nucleic acids which are the building blocks of RNA and DNA as well as protoplasm, a key component of cells.

In summary, a plant's survival depends on its access to nitrogen. In the short term, if nitrogen is unavailable from an external source, the plant will accumulate a much higher amount of starch (stored energy), which will create hardening in the plant's structures. This hardening makes crops unusable for food production.



Nitrogen is used to make amino acids which join together in chains to form proteins

Nitrogen Toxicity

Once a plant has passed from vegetative growth into the flowering cycle, its nitrogen needs decrease. A nutrient solution must account for this, either through calculation of uptake over time, or by making manual changes to it.

Plants with nitrogen toxicity show:

- Dark green colouring with dense or abundant foliage
- Restricted root systems
- Potential developmental problems in flowering and seed production
- Plants with excess nitrogen uptake may also show softer tissues, or loss of rigidity, which creates problems with flowering and fruiting, and may fail to yield. This is because excess nitrogen will upset the balance between starch and nitrogen, and result in less starch deposit in plant cell walls.

Excess nitrogen may also negatively impact phosphorus absorption.

Phosphorus (P)

Phosphorus comprises approximately 0.2% of the dry weight of most plants. It is an essential and limiting factor in plant growth and plays a vital role in plant metabolism and energy transport.

Phosphorus Deficiency

Plants deficient in phosphorus show:

- Stunted growth
- Often they are dark green in colour
- Potential accumulation of anthocyanin pigments (observed in blue-purplish coloration of leaf edges, stems, etc.)
- Delayed maturation

Note that deficiency symptoms often show in mature leaves first.

Phosphorus, like nitrogen, is an essential component of photosynthesis. While the finer details of photosynthesis are outside the scope of this book, photosynthesis takes place in two stages:

1. Light-dependent reactions
2. Light-independent reactions (also known as the Calvin cycle, or the dark reactions)

Phosphorus is necessary in the second stage, the light independent reactions. Adenosine triphosphate, or ATP, carries phosphate energy which is necessary for the production of food for the plant. ATP and its partner, adenosine diphosphate, are also used to carry energy and work with other physiological processes in the plant. If the plant is lacking phosphorus, it cannot grow properly which is why the first major symptom of phosphorus deficiency is stunted growth. Over time, this translates to delayed maturation.

Plants under phosphorus stress commonly display darker green foliage due to build-up of carbohydrates as carbohydrate use is significantly slowed. This is because while photosynthesis and starch creation can still occur, carrying energy around the plant becomes difficult without phosphorus due to its role in the transformation of sugars and starches.

Phosphorus Toxicity

Plants with phosphorus toxicity show:

- Potential iron deficiency
- Potential zinc deficiency

High concentrations of phosphorus can block uptake of iron and zinc which are needed for other plant processes. This blocking action will result in iron and/or zinc deficiency, regardless of their soil concentrations.

Potassium (K)

Potassium is necessary to plant development. It is a necessary cofactor for many essential processes within the plant. This means that potassium must be present for enzymes to drive key chemical processes. It also helps keep the necessary pH balance within the plant and pH is important in regulating a plant's chemical processes. If the pH is too low or too high, enzymatic reactions will be less efficient.

Potassium also regulates when the plant's stomata open, which are the tiny pores through which a plant takes in carbon dioxide and releases oxygen. Carbon dioxide is necessary for photosynthesis. Without adequate supply, the plant will be unable to synthesise energy.

Potassium is necessary for:

- Transport of sugars (via phloem)
- Transport of water (via xylem)
- Protein synthesis (necessary for the mechanism of chaining amino acids together to form proteins)
- Starch synthesis (storing energy from photosynthesis)

This means potassium is vital for plant life and growth.

Potassium Deficiency

Plants deficient in potassium show:

- Dark necrotic lesions on leaves (dicots)
- Scorch along leaf tips and margins (monocots)
- Potential weakening of stems, weak stalks (in corn, weak stalks, and a higher probability of lodging)

Necrotic is the adjectival form of the noun necrosis, which is a technical term for cell death. The necrotic leaf lesions found in potassium-deficient dicotyledons are the result of improperly functioning cellular mechanisms. Without potassium, many cell reactions and protein synthesis cannot take place, which ultimately results in cell death. Moreover, potassium is necessary for transport through xylem and phloem, meaning tissues do not receive adequate water and nutrition for survival, which will also lead to cell death. The scorch seen in monocotyledons is also a result of cell death.

Potassium is also important in maintaining production of the energy-carrying molecule ATP. Without ATP, the plant cannot produce sugars during stage 2 of photosynthesis (the dark reactions, also known as the Calvin cycle).

Weakened stems are caused by changes in turgor pressure (also known as hydrostatic pressure). Turgor pressure is the force of water pushing the cellular membrane into the cell wall. It is necessary for strong stems. This pressure is maintained through osmosis, usually using potassium and chlorine. In the absence of potassium, turgor pressure may be inadequately maintained, leading to weakened stems.

Potassium Toxicity

Plants with potassium toxicity show:

- In oranges, coarse fruit
- Potential magnesium deficiency
- Potential manganese deficiency
- Potential zinc deficiency

- Potential iron deficiency

Other Common Deficiencies and Toxicities

This section discusses other essential elements for plant growth. While these minerals contribute to plant health, they are secondary nutrients, and are less likely to affect crop growth.

Sulphur (S)

Sulphur Deficiency

Sulphur deficiency is quite rare, but it can be an issue in soilless culture, as soil mechanisms are not present to provide or mitigate supply.

Plants deficient in sulphur show:

- Light yellowing of leaves, especially younger leaves
- Longer roots
- Stems may become woody

Sulphur Toxicity

Plants with sulphur toxicity show:

- Reduced growth and leaf size
- Premature leaf death

Magnesium (Mg)

Magnesium Deficiency

Plants deficient in magnesium show:

- Interveinal chlorosis in older leaves
- Older leaf death (severe)
- Chlorosis of entire plant (severe)

Magnesium Toxicity

In the early 21st century, no specific symptoms of magnesium toxicity are known.

Calcium (Ca)

Calcium is especially important in soil culture because it has a role in both soil and plant health. In soilless culture, required calcium concentrations will be lower. Calcium is commonly found in municipal water and well water; this must be accounted for when calculating nutrient mixes.

Calcium Deficiency

Plants deficient in calcium show:

- Inhibition of bud development, shoot death
- Root tip death
- Distortion of young leaves, small size
- Young leaves display irregular margins, spotted or necrotic areas

Calcium is necessary for strong cell walls and membranes. It is not easily moved about within the plant system, which means newer growth is often inhibited, resulting in shoot death and slowed bud development. Poor cellular structure also affects root tips, and may lead to distorted leaves, or leaves showing cell death (necrosis), most likely due to a lack of integrity.

Calcium Toxicity

Plants with calcium toxicity show:

- Potential magnesium deficiency
- Potential potassium deficiency

Micronutrients

These minerals are important to plant growth, but amounts required are quite small. This means deficiencies may be less common. This section will address only the essential parts of each micronutrient's role.

Iron

Iron is a catalyst for chlorophyll production. Without it, the plant cannot photosynthesise and produce necessary carbohydrates for energy. Iron is also important in other plant processes.

Iron Deficiency

Plants deficient in iron show:

- Interveinal chlorosis of younger leaves
- Chlorosis of the whole plant (severe)

Iron Toxicity

Plants with iron toxicity show:

- Leaf bronzing
- Potential brown spots on leaves

It should be noted that true iron deficiency is quite rare; pH and other nutrient levels should be assessed first.

Chlorine

Chlorine Deficiency

Plants deficient in chlorine show:

- Leaf wilting, leading to leaf chlorosis and necrosis
- Roots become stunted, and may display thickening of the root tip

Chlorine Toxicity

Plants with chlorine toxicity show:

- Burning or firing in leaf tips and margins
- Potential chlorosis
- Smaller leaves, smaller plants

Manganese

Manganese Deficiency

Plants deficient in manganese show:

Stunted growth

- Interveinal chlorosis (younger leaves and older leaves, species dependent)
- Potential necrotic lesions (severe)
- Potential lead shedding (severe)
- Disorganisation of lamellae (chloroplast structures)

Manganese Toxicity

Plants with manganese toxicity show:

- Potential chlorosis
- Uneven chlorophyll distribution (appears as uneven greening)
- Reduced growth
- Stunted growth
- Leaf abscission
- Distortion and/or puckering of leaf margins

Zinc Toxicity

Plants with zinc toxicity show:

- Iron deficiency, causing chlorosis or bronzing
- Death

Boron

Boron Deficiency

Symptoms vary across species. Generally speaking, plants deficient in boron show:

- Stem death
- Root tip death
- Tissue disintegration (internal, displays as rot)
- Abnormalities in growing points, leading to stunted growth
- Brittle leaves and stems

Boron Toxicity

Plants with boron toxicity show:

- Leaf tip yellowing, leading to leaf necrosis in tip and margins, moving inward, until abscission

Zinc

Zinc Deficiency

Plants deficient in zinc show:

- Interveinal chlorosis in young leaves

Copper

Copper is an important component of chlorophyll production.

Copper Deficiency

Plants deficient in copper show:

- Distorted younger leaves
- Stunted growth
- Reduced yield
- Growing tip death

Copper Toxicity

Plants with copper toxicity show:

- Potential iron deficiency and chlorosis, bronzing
- Reduced or stunted growth
- Reduction in branching
- Darkening and increased thickness in rootlets

Molybdenum

Molybdenum Deficiency

Plants deficient in molybdenum show:

- Interveinal chlorosis, older leaves progressing to younger ones
- Twisted younger leaves, followed by leaf death

Molybdenum Toxicity

Plants with molybdenum toxicity show:

- Species-dependent leaf discoloration

What are the Most Common Symptoms?

Roots

Copper toxicity: stunting or thickening of roots.

Calcium deficiency: stunted root tip growth, softened roots, dieback of roots in extreme cases.

Aluminium toxicity: stunted root growth.

Shoots

Copper deficiency: unopened new shoots; necrosis of the leaf tips, distorted young leaves, pale coloured leaves and plant in general.

Calcium deficiency: stunting of new shoots, withering of new shoots, death of new shoots, collapsing stems, plant very green in colour.

Boron deficiency: pale green to yellow young leaves on a dark green plant, necrosis of the tips, rosetting or dieback.

Leaves (New)

Manganese deficiency: yellow or pale leaves on green plant with interveinal chlorosis similar to iron deficiency (below).

Iron deficiency: yellowing between the veins on new leaves or sometimes leaves entirely white with necrotic margins.

Magnesium deficiency: stunted new and middle aged leaves occasionally rosetted.

Molybdenum deficiency or nitrate, ammonium toxicity: old yellow, necrotic leaves on a green plant.

Zinc deficiency: pale, occasionally grey, new and middle aged leaves, leaves stunted and sometimes rosette.

Leaves (Old) or Entire Plant

Nitrogen/sulphur deficiency: pale plant, old leaves yellow, necrotic leaves, sometimes red petioles, or red undersides of leaves.

Potassium deficiency: plant pale green, leaves with yellow spots turning necrotic on margins or leaf blades.

Phosphorus deficiency: dark green plant with reddish/blue hue to the leaves petioles red.

Key to Detecting Deficiencies and Toxicities

An important means of managing the nutrient requirements of your plants is the ability to recognise signs of nutrient deficiencies or toxicities, ideally as early as possible so that such problems can be rectified with minimal impact on crop yields. Such recognition can be aided by the use of simple keys such as the following one.

Key to Symptoms of Nutrient Deficiency		
Symptoms		**Deficiency**
A.	Lower leaves mainly affected. The effect may occur on one part or over the whole plant.	
B.	Effects appear over whole plant; lower leaves go dry; foliage turns light or dark green.	
C.	Plant light green, lower leaves yellow, drying to light brown colour, stalks short and slender if element is deficient in later growth stages.	Nitrogen
CC.	Plant dark green, often develops red and purple colour, lower leaves sometimes yellow, drying to greenish brown or black.	Phosphorus
BB.	Effects mostly localised; mottling or chlorosis with or without spots of dead tissue on lower leaves, little or no drying up of lower leaves.	
C.	Mottled or chlorotic leaves, typically may redden, sometimes with dead spots, tips and margins turned and cupped upwards, stalks slender.	Magnesium
CC.	Mottled or chlorotic leaves with large or small spots of dead tissue.	
D.	Spots of dead tissue small, usually on tips and between veins, more marked at margins of leaves.	Potassium

Key to Symptoms of Nutrient Deficiency

Symptoms		Deficiency
DD.	Spots spread over the whole plant, rapidly enlarging; they commonly affect areas between also; leaves thick, stalks develop shortened internodes.	Zinc
AA.	Newer or bud leaves affected, symptoms localised.	
B.	Terminal bud dies, following appearance of distortion at tips or base of young leaves.	
C.	Young leaves of terminal bud at first hooked finally dying back at tips and margins, stalk finally dies at terminal bud.	Calcium
CC.	Young leaves of terminal bud become light green at bases and finally break down here, later growth leaves become twisted, stalk finally dies back at terminal bud.	Boron
BB.	Terminal bud commonly remains alive	
D.	Young leaves permanently wilted without spotting or marked chlorosis, stalk just below tip will bend over in acute deficiency.	Copper
DD.	Young leaves not wilted.	
E.	Dead spots uncommon, young leaves chlorotic, main veins green, yellowing can spread to older leaves.	Iron
EE.	Young leaves and veins yellow.	Sulphur
EEE.	Dead spots scattered over leaf, smallest veins green giving checkered effect.	Manganese

CHAPTER 11 NUTRIENT SOLUTION AND PRODUCE NUTRITION

In the past there has been concern raised that plants grown in soilless systems such as hydroponics could be deficient in some of the minerals people need for good health. These assertions have largely been found to be untrue.

Nutrient solution flows from a feed at the top of these NFT channels, and collects in the plastic tub; from where it can be pumped back to the top again.

Examples of Nutrient Solution Manipulation and Produce Nutrition

Higher animals such as humans require elements like sodium, iodine, cobalt, selenium, silicon, chromium, tin, vanadium and fluorine in minute quantities. We obtain these nutrients from the food we eat and while many are certainly present in animal products consumed, we also get a certain amount from plant material. Many of the crops we eat contain these extra elements required for our health, though they may not necessarily be essential for the plant itself. Research has actually shown that most hydroponically grown produce contains similar levels of elements to that grown in soil, and furthermore that hydroponics offers a means of producing nutritionally superior food through enrichment of the nutrient solution with certain beneficial elements. One example is the use of selenium to grow enriched vegetable crops to provide a healthy source of this element for human consumption.

Hydroponic nutrition and bioactive compounds

Bioactive compounds are ‘extranutritonal constituents’ which occur in very small quantities in food. These are additional to the fibre, carbohydrates, vitamins and minerals we associate with a healthy diet and a lot of bioactives are still undergoing intense investigation. Many researchers are now suggesting that while it has been possible to extract useful biochemicals from some foods to create supplements in tablet form, these are not as effective as when the phytochemicals themselves are eaten in their natural food source. It is likely that the benefit of bioactive compounds comes from additive and synergistic effects when the whole food is eaten, rather than the activity of an isolated compound.

It is commonly known that the quality of fresh produce in terms of appearance, flavour, fibre, vitamins and minerals is dependent on the conditions it was grown under. However, research has also shown that the bioactive content of fruits and vegetables is also influenced by a number of key factors such as genetics (cultivar selected), environmental conditions such as light, temperature, humidity, CO_2 levels, water stress, nutrition and the effects of pests and diseases. Determining which growth factors will have the greatest effect on increasing the health-giving compounds in hydroponic plants is not as simple as just providing optimum growing conditions. In fact, many of the beneficial phytochemicals in plants are produced in greater concentrations when the plant is under stress, something we usually try to avoid with a carefully tended hydroponic crop.

A good example of this is with hydroponic tomato crops. One of the most potent and well known antioxidants, lycopene, has been found to increase when hydroponic tomato plants are grown under osmotic or salt stress created with a high nutrient solution EC in the root zone. Tomato plants grown at a high nutrient EC of 4.5 mS cm-1, compared to 2.3 mS cm-1, were found to have an increase in lycopene concentration of 30-40%. If we couple this with the fact that different tomato cultivars have widely varying, naturally occurring levels of lycopene anyway, it is possible to grow ‘super food’ tomato fruit.

Lycopene is generally highest in tomato cultivars with the darkest red skin and this includes many of the varieties listed as ‘black types’ which have purplish skin coloration. While some of these darker skinned tomato types are being grown commercially, there is a wide range of older, heirloom varieties which have been proven to be many times higher in lycopene than standard red commercial hybrid tomato fruit. By combining a variety with a naturally high level of lycopene with increased nutrient EC conditions to supply some slight stress, the bioactive levels in the fruit could potentially be boosted many times higher than the standard red home-grown tomato. In fact, commercial tomato producers have started to take advantage of the increased consumer awareness of lycopene levels and some are growing hybrids specifically bred for higher levels of this compound. These ‘high lycopene’ tomatoes are being marketed and sold in mainstream grocery stores as a ‘functional food’ making them a potentially profitable hydroponic niche crop for greenhouse growers.

A similar effect has been found with hydroponically grown broccoli. Levels of phytochemicals with biological activity in broccoli are a result of both the genetics of the plant and environmental factors. When hydroponic broccoli plants were grown with some applied stress in the form of nutrient solution salinity (increasing the EC of the nutrient with sodium chloride), levels of certain bioactive compounds increased which helped to produce a health-promoting food.

The bioactive organosulphur compounds occurring in onions, garlic and other alliums can also be manipulated with use of hydroponic techniques. The concentration of organosulphur compounds in allium plants is due to the large quantities of sulphur (S) that accumulate as the plant grows. Sulphur concentrations in excess of one percent on a dry weight basis have been reported in bulbing alliums and much of this is partitioned into the healthy organosulphur compounds. The concentration of these important organosulphur compounds in alliums can be increased under hydroponic production with use of increased sulphur (S) and nitrogen (N) fertilisation. Studies have found that certain organosulphur compounds increase linearly with increasing N levels in hydroponic trials, and garlic also responds in a similar way to increasing S and N in the nutrient solution when grown hydroponically. This not only produces bulbs with a greater health value, but also increased flavour and pungency.

Hydroponic brassica crops such as watercress, Asian mustards and greens, kale and a diverse range of other brassicas are part of a growing awareness of the additional health aspects that hydroponic nutrition can deliver. Glucosinolates are an important group of bioactive compounds which are found in high concentrations in cruciferous vegetables such as broccoli, cabbage, kale, watercress, wasabi, Brussels sprouts, mustard and cress. These compounds, which are converted into isothiocyanates during food preparation, have been studied for their cancer fighting properties as well as other medicinal activity. Research studies have shown that hydroponically grown brassicas respond well to manipulation of the nutrient solution to improve their compositional quality and levels of bioactive compounds.

Use of nutrient solution EC for hydroponic quality improvement

Bringing EC levels of the nutrient solution in the root zone up just as the plant has passed the vegetative stage and has set the first fruit, is a common practice in commercial hydroponic tomato crops. This has been shown to have number of positive effects such as improving the compositional quality in terms of flavour, sweetness and volatiles, and also prolonging shelf life and firmness which are important post-harvest factors. Modern tomato hybrids bred for greenhouse and hydroponic production are particularly tolerant to high EC levels and respond well to this technique of quality improvement. Heirloom and older tomato varieties can also respond to increases in EC to maximise flavour, however not to the same extent as commercial hybrids, and they can become more prone to disorders such as blossom end rot when this is attempted. In hydroponic tomatoes, it has been found that the flavour profile, sugar, acid and sodium content of fruit grown at an EC of 8.0 mS cm-1 was far greater than fruit grown at an EC of 3.0. However, increasing the EC to improve flavour via a higher percentage of dry matter in the fruit tends to give smaller fruit and lower yields. So, there is often a trade off between flavour improvements and yield potential.

With hydroponic chilli crops, EC levels as high as 8.0 mS cm-1 have been applied to boost pungency with good results, however different chilli cultivars will respond differently to increases in EC and growers need to determine for themselves which will give the biggest ‘kick’ in their fruit. When using a higher EC to increases the pungency of chillies it is best to do this by increasing only the macronutrients in solution (N, P, K, S and Ca) and maintain the trace elements at normal EC strength levels.

For crops such as onions, garlic, shallots and chives the strong flavour and aroma is derived from the presence of organosulphur compounds. In hydroponic allium crops, these distinctive flavours have been shown to be boosted by using higher levels of N and S in the nutrient solution. Brassica crops such as watercress, arugula, cabbage, kale and others also derive much of this distinctive flavour from sulphur-containing compounds called ‘glucosinoles’. Manipulation of sulphur in the nutrient solution can help boost these flavours which range from cabbage-like to peppery and pungent in watercress, to sharp and nutty in arugula. Increasing sulphur levels in hydroponics have also been shown to assist flavour or pungency in condiment herbs such as wasabi or horse radish which contain mixtures of volatile compounds like isothiocyanates which give them their flavour and heat.

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