Fundamental management of hydroponic systems

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This paper is intended as an important guide to people starting or considering going into commercial hydroponics and as a refresher to existing hydroponic growers.

Horticultural skills

Particularly new and intending growers need to take care to not be blinded by 'hydroponic technology'. While the technology is important, having a good working knowledge of horticultural art and science is hugely more important.

In my opinion, the '80/20 Rule' applies here. Of the growing skills required to grow a good commercial intensive horticultural crop, about 80% relate to horticultural skills and only about 20% to hydroponic skills. Put another way: if you grow cucumbers, you are a cucumber grower using a hydroponic technique, rather than a hydroponic grower growing cucumbers.

In general, the best we can aim for it to provide ideal conditions in the root zone for the plant to perform as well as possible. Remember that the hydroponic system only works through the root zone, and the aerial portion of the plant has the major influence on the plant's performance.

The major foods of the plant are carbon dioxide (CO_2) and water (H_2O). When acted on by sunlight the plant leaves combine these (through the process of photosynthesis) to produce sugars and emit oxygen (O_2). These sugars are the bulk food of the plant. The nutrients you add are only a part of the plant's food needs and could be considered as equivalent to the vitamins and minerals we need.

Environmental control

Controlling the environment effectively is the single most important aspect of achieving maximum production of a particular crop. Growers need to make the best use of the equipment they have. This means acquiring a good knowledge of the settings to get optimum results and continuously checking the actual conditions achieved.

Pests and diseases

Ideal growing conditions in a greenhouse usually mean they will also be ideal for some pests. Identifying pests as early as possible and knowing how to sensibly control them, preferably using IPM, is a critical horticultural skill.

While a well managed hydroponic system can usually avoid soil borne root diseases (often a major reason to go hydroponic - to get out of disease prone soil) this is not always so. Also, a properly controlled environment can greatly reduce the risk of developing some diseases, especially mildews. However, diseases can still be a major problem, and can be spread by insects and workers. Again, a grower must acquire the skill to recognise disease risks and use preventative measures, including good hygiene practices, to reduce the risk.

Crop culture

By this is meant the management of the plant. This may include aspects such as: propagating technique, time of planting, plant density, crop support, training plants (such as up strings), initiating flowering, pollinating, pruning, disbudding, deleafing, truss pruning, balancing leaf area and fruit load, manipulating vegetative and generative influences, stage of flower/fruit development for harvest, timing when to stop the plants, etc, etc.

Quality control

While not every grower is quality assured, this is becoming an ever increasing requirement. However, every good grower should have an interest in using quality control techniques to ensure the best results are achieved and problems can be traced.

Other skills

This paper is concentrating upon growing skills, especially hydroponic management. However, as for any small business there is a need for many other skills if your business is to be successful.

The full range of management skills is needed: planning, financial, staff, repairs and maintenance, etc.

Once everything else is in place, ultimate and ongoing success will eventually depend upon successful marketing. That is, can you sell your produce for a price that gives you a reasonable return?

Hydroponic systems

There are two basic types of hydroponic systems – 'open' and 'closed'. This paper will mainly consider systems used commercially in Australia. More detailed descriptions are given in many hydroponic books.

Open systems

In open systems the nutrient solution is distributed into the system and a proportion of this is run off and not recirculated. Open systems, also known as free drainage or non-recirculating systems, all use soilless media. The medium is loaded into small containers such as pots, upright bags, or pillow bags, which have the advantage of reducing evaporative loss from the bag. They are usually fed intermittently through drippers with some excess free drainage.

There are a wide range of media used, the major ones in Australia being rockwool, sand, perlite, sawdust, and cocopeat. Others used include scoria, expended clay, and peat.

Closed systems

There are several types of closed systems, also known as recirculating systems. The most common are NFT (nutrient film technique) and media based systems similar to the open type, but with the drainage recycled. NFT is a continuous flow system. Solution is fed from a holding tank into, and flows down sloped channels and is then recycled to the tank where the solution is topped up.

There are several other types of closed systems that are rarely used here. These are the 'Autopot' and 'Gericke' demand fed systems, and aeroponics. 'Flood and drain' or 'ebb and flow' systems with intermittently fed gravel channels and beds, have largely been displaced, however the technique is often used for propagation.

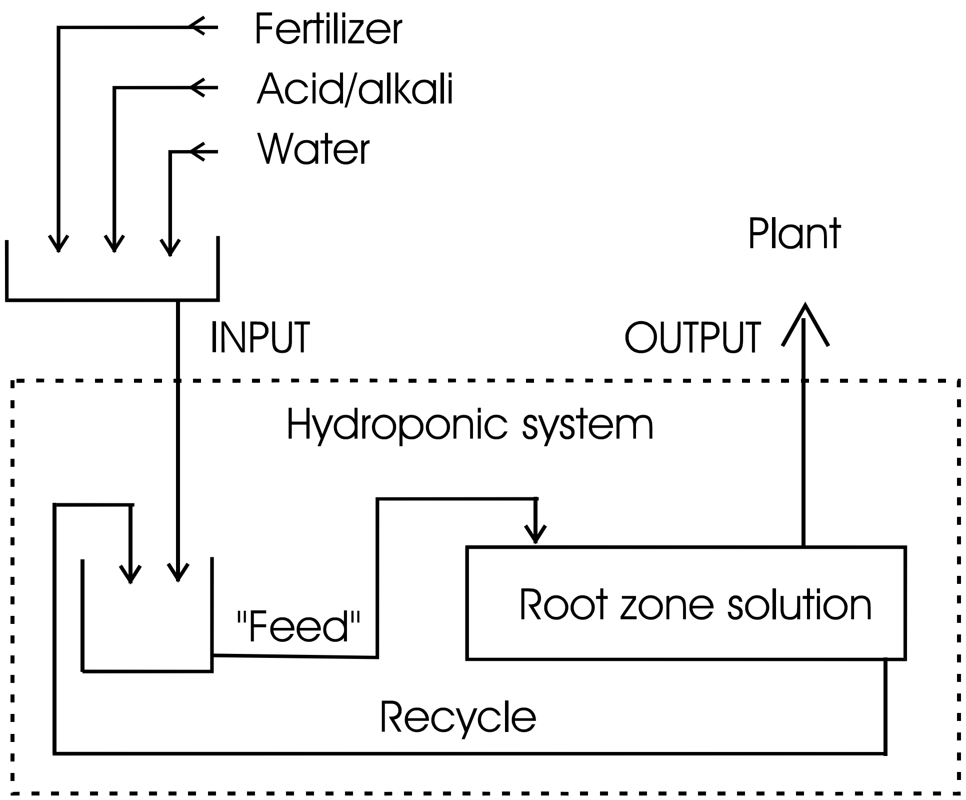

Figure 1. Flow diagram for a closed (recirculating) hydroponic system

Factors for selecting a system

There is no universal hydroponic system that best suits all crops, so the first stage in your planning cycle is to decide upon which crop you will grow.

For short term crops such as lettuce and herbs the common choice is NFT. The typical Australian system has several approximately 100 mm wide channels laid out as tables, which has a major advantage of being at a good working height. NFT is rarely used for longer term crops with the exception of tomatoes, for which it is quite popular in New Zealand.

For longer term vegetable and flower crops, especially those vulnerable to root disease, the common choice is media-based systems, either open, or closed with disinfection in the recycle loop.

Some factors to consider when deciding on a system are:- how successful has the system been for your crop, environment and water quality; what level of expertise is needed; reliability; versatility; life span; ease of control; ease of cultivation and harvesting; ability to improve crop turnaround; delivered cost; installation cost; replacement cost; operating and maintenance costs, including the costs of planting and removing each crop and sterilising if necessary; availability of technical support and advice.

System design

Basic Requirements

The most important requirement of all hydroponic systems is that the needs of the plant roots must be fully satisfied. That is the plant roots are to be provided with:

- adequate water,
- adequate oxygen,
- adequate balanced nutrients,
- sufficient void space volume for the mature plant roots.

Many different factors influence the availability of these vital ingredients. These factors can be placed into two groups:

Firstly, the factors involved in the supply of adequate water and balanced nutrients to the roots are mainly those associated with the operation of the system. Factors associated with its installation have a relatively minor effect.

Secondly, the factors involved in the supply of adequate oxygen to the roots are mainly those associated with the installation of the system and will be discussed further below. Factors associated with its operation have a relatively minor effect, but poor management of aeration can bring major problems.

There are also other aspects which influence the performance of the root zone and should not be ignored. The more important of these are:-

- the presence of plant pathogens,
- the temperature of the root zone,
- the removal of respiration products and exudates from the roots,

While these are not as basic as the provision of water, oxygen and nutrients, they each have the capability of causing disastrous crop losses under adverse conditions. These factors must be considered in the design stage.

For example, sterilisation is essential for water of doubtful biological quality, such as from a dam, creek or irrigation channel and recycled hydroponic solution. Also high temperatures in the root zone can cause major problems including crop loss. Techniques particularly susceptible to temperature rise in hot climates, such as NFT, may need to have a solution cooler installed.

Water supply

Having an adequate permanent water supply of acceptable quality is a vital first priority for setting up a hydroponic farm. Have the water analysed both chemically and biologically. Water taken direct from farm dams, irrigation channels or streams should be sterilised to reduce the risk of disease. Water with high dissolved salts, especially sodium chloride, isn't suitable for closed systems, unless it is made useable by installing reverse osmosis equipment. This will be discussed again later.

Media properties

There are a wide range of growing media available which are suitable for hydroponics. When considering which to use it is important to evaluate their properties as well as their cost.

A critical property of a medium is its usable void space because this influences its air and water holding capacities. For particulate media the size distribution impacts upon its void space. The more mixed in size the lower the void space. The percentage void space and their air and water holding capacities vary considerably. For example, at the high end rockwool at 97 % void space, and at the low end mixed sand at probably under 40 % void space. Therefore to have the same volume available for the plant roots and water and air, more than double the volume of sand per plant would need to be used.

The capillary properties of media differ, resulting in different air/water holding capacities. For all media the air / water characteristics will change with height. There will always be a reduction in water holding capacity with increasing height, and consequently an increase in aeration. The pattern of this change will be specific for each medium.

Because of this, the volume of each medium should be considered individually, as should the optimum height for that medium for that crop. Different crops are known to have different aeration requirements, especially at the crown. For example, cucumbers and gerberas need higher aeration at the crown than tomatoes and roses. This higher aeration can be obtained by increasing the height of the medium, or choosing one with more suitable characteristics.

If the water holding capacity of a medium is low a reservoir is often added. Take care that this is not too deep (say 10mm maximum) or problems will probably arise from the resulting anaerobic (‘no air’) conditions.

Other characteristics to note are:

- freedom from pests, diseases and salts,
- stability with time,
- consistency,
- pH effects, and
- ease of installation and removal.

Channel systems

The basic theory behind the NFT (nutrient film technique) system is that a channel set up is used that enables a thin film to be maintained in the channel throughout the life of the crop. The thin film should enable the dissolved oxygen taken up by the plants to be replaced in the water film because of the relatively large surface area available.

In practice growers need to be careful that their channel set up can achieve this, especially for a mature crop. The basic aim is that the solution flowing down the channel must still contain adequate dissolved oxygen when it reaches the end of the channel. There are factors involved which interact and need to be considered. To reduce the risk of problems developing, these are:

- a channel shape to give a relatively flat film, that is, flat rather than round,
- length shorter rather than longer,
- slope steeper rather than flatter, usually a minimum of 1 in 40.
- a sensible flow rate.

Note that if you plan a trial, use the same geometry on the final commercial set up. I have seen where successful trials led to commercial failures because the final channels were made longer. Also grow through a full crop, because failure is most likely to occur at heavy fruit load when oxygen demand increases.

Equipment

There is a wide range of equipment that can be used with hydroponic systems. Without detailing everything, there is one particularly vital aspect to remember.

All pipes, pumps, channels, containers, tanks, etc, that will come into contact with fertilisers or nutrient solutions must be made of inert material, usually plastic or sometimes stainless steel. Take care not to use brass fittings and or pumps, because they will not only corrode but may force the plants into copper toxicity. Galvanised tanks will cause similar problems with zinc toxicity, and also don't collect rainwater from galvanised roofs. Similarly don't use concrete tanks because these will give a large pH rise.

It also pays to carefully consider what backup systems you may need in case of power failure, for example.

Solution volume in open systems

The smaller the container size and the lower the volume of solution held per plant, the more difficult the system becomes to manage. Water content changes more rapidly, accompanied by EC rises and often pH swings. This forces the use of more frequent irrigation cycles, which may not be appropriate for your system.

Solution volume in closed systems

Similar to open systems, the lower the volume of solution held per plant, the more unstable the system can become. For systems without automatic pH and EC control, obviously these properties can be effected. However, other major properties to change significantly are solution temperature and nutrient balance, which can cause problems that are often not recognised. This similarly applies to systems without controllers.

Irrigation management

The first requirement in managing a hydroponic system is to ensure that the plants are getting the right amount of water. In simplest terms this means at least replacing what the plant has taken up.

Water demand

Water uptake by the plant roots is mainly in response to the plant's demands.

These are partly due to photosynthesis and the growth of the plant, but mainly caused by evaporation from the leaves and the movement of water through the plant, known as transpiration. Transpiration is mainly driven by solar radiation. However, it is also influenced by the condition of the air immediately around the leaves. The temperature, relative humidity and speed of movement of this air can all have a major impact.

The total water demand by a plant will depend upon its leaf area. Other aspects can also affect demand, such as pest or disease damage to the plant and/or its roots.

Table 1. Factors which influence water uptake

factor	**water uptake increases with:**
leaf area	greater effective leaf area (up to a limit)
radiation intensity	higher radiation intensity (up to a limit)
radiation duration	longer radiation duration
air temperature	higher temperature (to a limit)
relative humidity	lower relative humidity
wind	higher wind speed

Solar radiation is by far the single most strong driver of transpiration and hence water demand. Therefore its daily pattern is of critical importance. As seen from Figure 2, on a cloudless day it has a prolonged peak around noon and drops to nothing at sunrise and sunset.

It is critical that your irrigation system is capable of supplying this peak demand, with the required excess, and is set to do this. Failure to match demand during the peak will result in added stress on the plants and hence a loss in performance and possibly major problems.

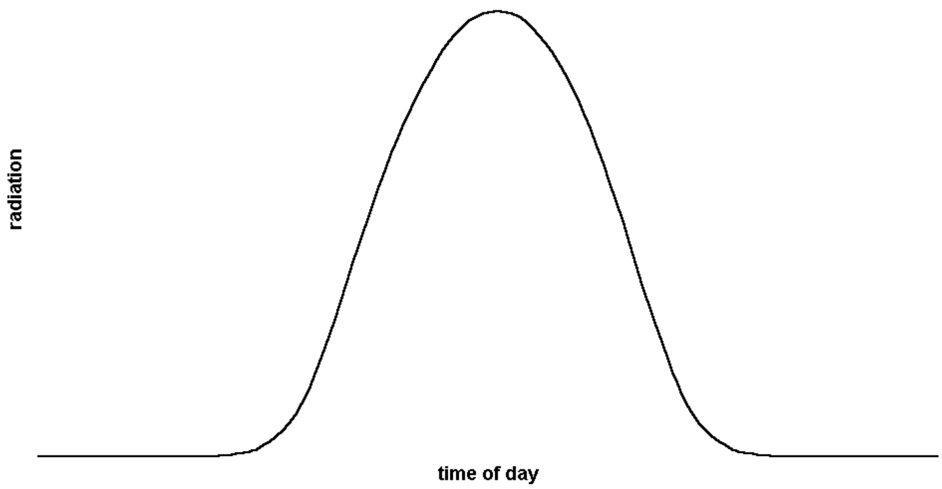

Figure 2. Solar radiation pattern over a day, for a cloudless sky

Of course, solar radiation is often not constant because of such influences as cloud cover. For this reason many irrigation controllers are based around a solar integrator to sum the solar radiation to trigger the next irrigation. Increasingly sophisticated versions of these controllers are being taken up by many growers.

However, solar radiation is not the only driver of transpiration and hence air temperature and relative humidity (often expressed as the driving force termed vapour pressure deficit, or humidity deficit) will maintain a small amount of transpiration through the night. This is often ignored, but some systems with accurate irrigation may supply one small irrigation during the night.

Air / water management

In media based systems and flood and drain systems, the frequency of watering has an impact on the variation in water and hence air content. The fewer the irrigations, that is the longer the cycle between irrigations, the larger the volume of feed needed per plant. Importantly, to go with this is a larger change in air/water content. For example, a three times longer cycle will give treble the drop in water content of the medium. In general plants perform better under steady conditions. That is, they are better fed 'little and often'.

In media based systems it may be possible to exert some control over the air/water ratio in the medium. In general plants respond better if there is higher aeration (that is, lower water content) in the root zone during the night.

This is even more important in winter, when too high a water content can lead to problems. Therefore it is common practice to aim for a maximum water content during summer and a much lower aim in winter. This and the day/night difference are also used as one of the factors to influence the vegetative/generative balance of the plant.

Control over the night-time water content is mainly achieved by adjusting the start times of the first and last irrigations of the day. Because of the little ongoing transpiration there will be an ongoing drop in water content over the night.

Electrical conductivity (EC) control

When fertilisers are dissolved in water they split into positively and negatively charged ions. This electrical activity increases the ability of the resulting solution to conduct electricity, the more fertiliser the greater is the effect. This property of a nutrient solution enables its strength to be conveniently measured by using an electrical conductivity meter.

Electrical conductivity (EC) is the most common means of expressing nutrient solution strength. Its most common units are milliSiemens per centimetre (mS/cm). Other units are also used. A CF meter reads in CF units, where 10 CF units = 1 mS/cm. Another type is a TDS (total dissolved solids) meter which gives a reading in ppm (parts per million). All of these apparently different meters actually all measure EC, but have an inbuilt conversion factor to give the required read out.

An important limitation of EC is that it only gives a measure of total nutrient strength and indicates nothing of the balance of individual nutrient ions. It also measures only the total ionic constituents of a solution, not any non-ionic or organic solutes such as some root exudates.

The most important principle of EC management, which is often not realised, is that it is the solution around the root zone which must be managed. In most systems the root zone EC will be different to that of the feed.

Effect of EC upon yield

The typical response of crop yield to different ECs is as follows:

Low EC gives a low yield which then rises to a maximum as the EC is increased. This maximum is usually a plateau rather than a peak. Further increases lead to a drop off in yield and eventually to crop failure. Values of EC and the shape of the curve will differ considerably for different crops, and even different varieties. The effects of climate and light will also change the curve. However, in general, for most crops there will be no significant differences in yield over a wide range of EC.

Note that the EC referred to is that of the root zone solution around the plant roots. Remember that in most systems this can be quite different to the EC of the feed.

Effect of EC upon quality

Having higher EC around the roots results in an increase in the strength of the plant internal fluids. This gives hydroponics its most effective means of influencing the plant's quality.

Very low EC (say less than 1.0 mS/cm) around the roots will give a relatively soft plant. Lettuce will be relatively soft, as will tomatoes and other vegetables and fruit. The shelf life of vegetables and the vase life of flowers are usually lower under these conditions. Taste can also be inferior.

Conversely, increasing EC usually gives stronger plant fluids and hence higher dry matter in leaves, fruit and flowers along with higher sugars and other organic compounds, inorganic nutrients, and acidity. Within limits these usually lead to improved taste, firmer fruit, and improved shelf life of vegetables and fruits, and stronger stems and flowers and improved shelf life for flowers. However, for some products such as lettuce, a soft product may well be preferred to a harder one.

The response of quality to increasing EC often shows a similar pattern to that of yield. Quality rises to a maximum, which often covers a wide range of EC, then falls again. However, another common pattern is for quality to still be gradually improving with increased EC to well past the point of reduction of yield. This is particularly the case with fruit such as tomatoes. Different aspects of quality will probably respond differently to increasing EC.

If you are tempted to try a high EC technique commercially, then you need to trial it very carefully first. High EC will make the plant more susceptible to calcium deficiency in periods of low transpiration or high temperature. This can lead to blossom end rot in tomatoes and tip burn in lettuce. Also, very few other crops respond as favourably as tomatoes to high EC. In particular, sodium chloride can be toxic to many plants, such as lettuce, capsicum, strawberries, roses, etc.

EC control in open systems

EC is more difficult to manage in open systems than in recirculating systems, especially continuous flow systems. This is because the EC does not remain steady within the systems or even the individual containers of medium.

For most crops a typical feed solution would come through the drippers at a strength of say EC 2.0 mS/cm. However, the uptake of water by the plant due to transpiration is higher than the its uptake of nutrients. With more water than nutrient being taken from the root zone, the result is that the strength of the solution left in the root-zone gets stronger, that is, its EC rises.

As each successive volume of feed irrigation comes from the dripper it wets a zone under the dripper and displaces the previous irrigation volume, which has also been depleted a little by plant uptake. Over time there will be a succession of irrigation volumes making their way through the medium, heading towards the container outlet(s). All this time their volume would have been shrinking and their EC rising. By the time it gets to the outlet to run off its EC may have risen to say 2.7 mS/cm. Its journey would also have taken a relatively long time.

How much the EC will rise between dripper and run-off is influenced by several factors:

- the higher the dripper EC the higher the EC rise,
- the higher the transpiration the higher the EC rise, for example in hot dry windy conditions.
- the lower the percentage run-off the higher the EC rise.

There will also be an EC pattern through the medium influenced by the shape of the container, the location of the dripper and the outlet(s), the properties of the medium and the percentage run-off. Because of this you need to be very careful if you are trying to get a sample of the root zone solution direct from the medium. A change of sampling point and you will probably get a different result, especially if you happen to pick a dead spot. This is one reason why EC management is difficult in these systems.

I have seen numerous poorly managed systems with a feed EC of say 3 mS/cm, in hot dry weather and with a low percent run-off, reach a run-off EC of over 10 mS/cm. These crops were tomatoes or carnations, which were damaged, but survived. Most other crops would have been dead under these conditions. How did this remain undetected? Because they weren't sampling and testing the run-off. Often they weren't even testing to see if there was any run-off at all.

Normally, they would finally recognise that there was a problem, give their systems a huge flush with straight water, and start again. This is very poor management, not only to have let it happen, but flushing is a bad technique. Their plants had adapted to some extent to high EC, they were then given a huge flush and dropped to virtually zero EC, and then given a gradual increase in EC from the feed. That is, from 'stuffed' to 'starved'. Then quite often the cycle would just start again.

The lessons from this are the vital need to measure the EC and volume of run-off, and calculate and control the percent run-off. Also, if there is an inescapable need to flush, it should be done with feed solution, possibly slightly weaker, so that the plants aren't completely starved of nutrient.

Irrigation frequency also has an impact. Similarly to water content variation, if there is a relatively long delay between irrigations the EC in the medium will rise higher.

EC control in closed systems

In continuous flow recirculating systems such as NFT EC management is particularly easy, especially with automatic EC control. Usually there is a water makeup value in the return tank and fertiliser is injected into the feed to bring its EC up to set point.

Dripper based recirculating systems normally run at about 40% run-off in order to minimise the volume of run-off to be treated before reuse. This means that it is approaching the difficulty of managing an open system, but not quite because it normally has a higher percent run-off.

Flood and drain systems are roughly in between in difficulty. The main aspect to beware is that the time between flooding cycles does not get too long, with a consequent EC rise.

pH control

pH is the scientific measure of the acidity of a solution. In practice it has no units. A pH of 7 is neutral. Above 7 is alkaline and below 7 is acid. Its scale is logarithmic, which means that every unit change in pH is a ten fold change in acidity.

In the soil, pH can be vital because of the many complex interactions that can occur. However, in hydroponic solutions the influence of pH is relatively minor in comparison. Many experts agree that anywhere in the pH range from 5 to 7, or even 7.5, is unlikely to cause significant problems. pH will cause major problems if it goes beyond these limits. The most common effects of high pH are iron and phosphorus deficiency. Low pH starts to give deficiencies, but can also start to dissolve some media, especially rockwool.

Overly careful attention to pH management isn't wrong in itself, but what does frequently lead to severe problems is a grower's belief that pH is the only important aspect of hydroponic management. This is dead wrong!

Other than in the case of extremes, the management of the nutrient solution balance, strength (that is, EC), and aeration are far more important than pH. Of the nutrition problems I see with some pH involvement, far more relate to problems caused by pH adjustment than to the pH drifting from some perceived optimum.

As with EC management the solution whose pH needs to be controlled is the root zone solution. Controlling the feed pH is only a means to this end, and needs to be tempered by the aspects discussed in the following sections.

Acid/alkali addition

If the pH of a feed solution needs to be lowered this can be done by adding acid. The acids commonly used are firstly phosphoric acid, secondly nitric acid (because it is nasty to handle). Rarely used, but a possibility, is sulphuric acid. Never use hydrochloric acid.

Less frequently the pH of a feed solution needs to be raised. This can be done by adding an alkali. Those commonly used are potassium bicarbonate, or if a stronger effect is needed, potassium hydroxide.

Caution - always take great care when handling concentrated acids or alkalis, especially to protect the skin and eyes - a full face mask is essential.

Apart from changing the pH, by adding acid/alkali you are also adding extra of one nutrient element and hance changing the nutrient balance. If the addition rate is steady, known, allowed for in calculating the formulation, and checked by analysis, this is OK. However, in practice many growers do not do this.

Sometimes nutrient solutions require the addition of relatively large quantities of (usually) acid. This will significantly boost the nutrient ion which comes in the acid. The effect of this can lead to problems, especially if phosphoric acid is used. The reason for this is that the intended level of phosphorus in the feed is relatively low, so any unplanned increase will have a severe impact. This can become very severe if it is a closed system. I have met cases in recirculating systems where, within two weeks, phosphorus levels have risen to over 200 ppm in the root zone solution instead of the intended 40 ppm, leading to major problems.

This effect can occur whether your pH control is automatic or manual.

Ammonium addition

The plant roots not only take up ions from the root zone solution, but they also exude ions (plus a wide range of organic compounds). The plant keeps itself electrically neutral. Therefore, if it is taking up more positively charged ions (such as ammonium $NH4^+$) than negatively charged ions it will exude positively charged hydrogen ions H^+. H^+ is the "acid" ion, and hence the pH of the root zone solution will fall.

The opposite effect takes place when there is a higher uptake of negatively charged ions (such as nitrate $NO3^-$) and hence the pH of the root zone solution will rise. This is common for many crops, especially during their early vegetative growth stage.

Because ammonium ions are taken up by the plant very much quicker than any of the other nutrients, increasing the proportion of ammonium in the feed will result in a relative lowering of the pH. Reducing the proportion of ammonium in the feed will result in a relative raising of the pH. This applies to all systems whether recirculating or not.

For example, the pH of your root-zone solution may be over 7 even though you have been pulling your feed solution pH down to well below 6. Note that in this situation the high acid input, especially if using phosphoric acid, can cause your root zone solution to get well out of balance as mentioned above. Increasing the ammonium in the feed should allow you to feed at about pH 6 and to maintain that level with time without adding excessive acid.

Whether using acid/alkali or ammonium for pH control, do not overdo trying for tight control. Often the safest approach is to allow a reasonable degree of pH drift rather than use excessive correction. In hydroponics tight pH control is rarely needed.

Beware that high levels of ammonium can be toxic to plants, in particular causing root death. Also, too high a level of added nitrogen can lead to soft growth. Up to 10% of the total nitrogen in the ammonium form is safe for most plants, dependant upon their stage of growth. It is very risky to go above 20%. Your calculated figure should include the ammonium that comes in the calcium nitrate (typically 1.1% N as ammonium).

Until recently the most common form of ammonium added to hydroponic solutions has been greenhouse grade ammonium nitrate. In Australia this now requires a special licence to buy and use, other than in liquid form. Substituting greenhouse grade ammonium sulphate is OK in open systems, but it is best to use liquid ammonium nitrate in closed systems.

Iron chelate

In the early years of commercial hydroponics, growers had major problems keeping enough iron (Fe) in solution. This was because the form they were using was ferrous (iron) sulphate, which would quickly oxidise to rust and drop out of solution. This problem was solved with the development of chelates which provide a protective shell around the iron.

The common form used is Fe-EDTA which contains about 13% Fe, however even this degrades gradually, especially at higher pH. Increasing numbers of growers now use more complex chelates with better stability such as Fe-EDDHA which contains 5% Fe.

Many of the other micro-nutrients (trace elements) are also available in chelate form. While these are increasing in use, most growers have no difficulty with using the standard non-chelated (mostly sulphate) forms.

pH meters

The weakest link in pH management is the probe of the pH meter. It is expensive and vulnerable and needs to be cared for properly. The glass in the electrode is porous and if it becomes blocked it won't function properly. The probe should not be allowed to dry out. Keep it standing in water, or if it has a cap keep a few drop of water in the cap to keep the humidity high. The electrode should never be touched by fingers as they are greasy.

The meter needs to be calibrated regularly, say weekly, using a pH buffer near your normal working range. Occasionally the meter should be fully calibrated using both high and low pH buffer.

When taking readings, the probe should be rinsed with water, and then the solution to be measured, before suspending it in the solution. Give the meter a little time to stabilise before taking the reading. If the reading seems strange, always recheck the meter before taking any action.

If you get a strange solution pH reading, check your meter with a buffer solution to ensure that it is reading correctly before you take any unusual corrective action.

Nutrient management

By nutrient management I am referring to management of the nutrient balance in the solution around the plant roots.

Most growers are aware of the importance of the nutrient balance of their feed solution. Unfortunately, many do not realise that the root zone solution usually has a quite different analysis to the feed and is much more important. The main function of the feed is to maintain the root zone solution at the ideal nutrient balance. Controlling the feed solution is not an end in itself. Blind emphasis on the feed solution, while ignoring the solution around the root system, is the underlying cause of most hydroponic nutritional problems.

There is a major difference between the ease of nutrient management in recirculating and non-recirculating systems. Without recirculation, provided the EC is kept under control, any nutrient imbalance which starts to build up goes out with the run-off. With recirculation the recycled nutrient solution imbalance continues to build with every pass, making nutrient management much more difficult .

A simple but important first step for a beginner is to ensure that you are using a hydroponic fertiliser. Occasionally new growers have given themselves huge problems by using a fertiliser intended for soil fertigation.

Concentrated solutions

For convenience, or when using automatic controllers, most commercial growers use concentrated nutrient solutions which are typically 100 times stronger than normal feed strength. These are then diluted 100 times just before feeding into the dripper pipes. At the high concentration it is essential to use a two part fertiliser, typically called parts "A" and "B".

The two parts are needed to separate the calcium ions from the phosphate and sulphate ions, which will otherwise precipitate out at that high concentration. When diluted to working strength, they dissolve quite readily. A very rough analogy is that you can dissolve one teaspoon of sugar in a cup of tea, but cannot dissolve 100 teaspoons of sugar in the same cup of tea. Part A contains all the calcium nitrate and usually the iron chelate, and part B all the phosphate and sulphate ions.

Plant nutrient content

Figure 4 indicates the generalised importance of individual nutrient element concentrations within the plant.

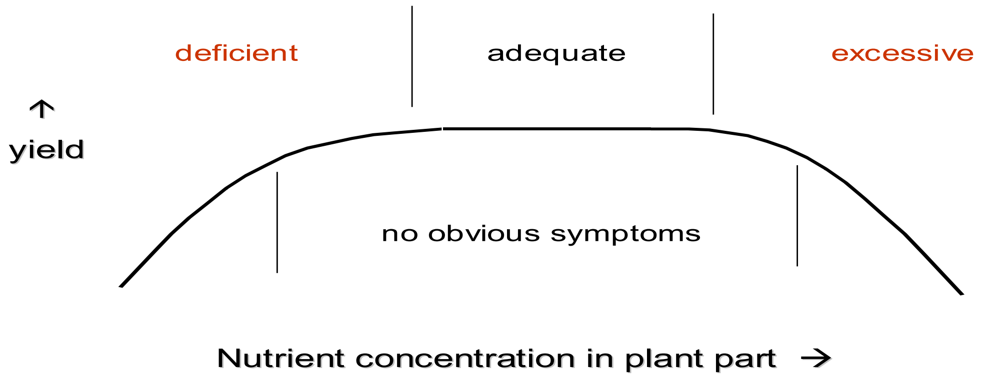

Figure 3. Yield v. nutrient concentration in plant.

This indicates two important aspects of nutrient management. Firstly, there is quite a wide range of nutrient concentrations which are acceptable for the plant to perform properly. Secondly, when an individual nutrient element gets to the deficient or toxic stage, there is some loss of yield before symptoms become apparent. In general a similar graph would apply to plant produce quality.

There is a similar pattern for the effect of nutrient balance within the root zone solution. That is, that there is a wide range of acceptable individual nutrient concentrations that is acceptable to the plant. Note that what is most important is the ratio of the individual nutrients, rather than their absolute values.

Ease of nutrient uptake

Even when the root zone solution contains a reasonable relative balance of nutrients (that is, nothing at deficient or toxic levels), there will be considerable difference between nutrients as to the apparent ease of their uptake. These are listed in Table 2.

Table 2. Apparent relative ease of nutrient uptake.

rate of uptake	nutrient
extremely fast	ammonium
very fast	phosphorus, manganese
fast	potassium
moderate	nitrate, iron, zinc, copper, molybdenum, boron
slow	calcium, magnesium, sulphur,

These relative uptakes have a major influence on the composition of the root zone solution needed to optimise nutrient uptake by the plant.

Root zone solution aim

The vital solution for the plant is what is around its roots. In order to optimise uptake it helps to allow for the ease of uptake of individual nutrients. Therefore, standard root zone solutions (say, as recommended by the Dutch) make allowance for these.

Consider the macronutrients in the root zone solution:

- Ammonium (N as NH4) is a special case added to control pH drift as was explained earlier.
- Because phosphorus (P as H2PO4) is easily taken up, its relative concentration is reduced in the root zone.
- Nitrate (N as NO3) is unchanged and potassium (K) reduced slightly.
- Calcium (Ca), magnesium (Mg), and sulphur (S) are substantially increased to help boost their uptake.

The intention of these changes is to optimise nutrient uptake and hence plant growth. The Dutch have recommendations for a range of hydroponic crops. While these were developed for their conditions, they are the best guide we have available. As an example I will use their recommendations for cucumbers, given in Table 3 below.

It is important to remember that the input solutions will have a different nutrient balance to the root zone nutrient solution.

Another important fact is that the aim nutrient balance for the root zone solution remains constant throughout the life of the crop. However, the input solution nutrient balance will probably change over the life of the crop. The recommended input solution is therefore only a base from which to work. It will be varied to allow for any pattern of change in the plant uptake and to adjust any developing imbalance in the root zone solution analysis.

Comparing input and root zone solutions

In Table 3 are the Dutch nutrient solution recommendations for cucumbers in rockwool, for both open ("free drainage") and closed ("re-use drainage water") systems.

Table 3. Dutch recommendations for cucumbers in closed and open systems - ppm.

nutrient	root zone solution – both systems	input solution – closed (recirculating)	input solution – open (free drain)
nitrate NO3 as N	252	269	282
phosphate H2PO4 as P	28	64	49
sulphate SO4 as S	112	53	55
ammonium NH4 as N	<7	23	23
potassium K	313	415	394
calcium Ca	261	181	201
magnesium Mg	73	40	42

Notes:
1. ppm = parts per million, equivalent to milligram/litre (mg/l).

2. Adapted from C Sonneveld, N Straver, "Nutrient solutions for vegetables and flowers grown in water or substrates", Research Station for Floriculture and Glasshouse Vegetables, Naaldwijk, the Netherlands.

3. All solutions adjusted to the same strength.

Open (free drainage) systems

The nutrient management of open systems is relatively easy, which is the major reason why they remain very popular, along with reduced risk of spread of root diseases.

As discussed before, there is a wide range of nutrient balance which will be acceptable to the plant. Provided the EC is being kept under control, then a moderately well balanced feed will keep the root zone solution from getting too far from standard. That is, it is run off before it gets too far out of balance.

It is still necessary for good management to regularly have full chemical analysis done to avoid the risk of imbalance developing. Especially where the plant nutrient demand changes with stage of growth, as with tomatoes, the feed needs to be adjusted to suit.

Closed (recirculating) systems

Recirculating systems have many advantages. However, one of their major problems is the difficulty of nutrient management, an aspect which is rarely mentioned in books and articles. Consequently many growers do not recognise the need for good nutrient management techniques, and can get into severe difficulties.

This is because, if the input feed is out of balance with the plant nutrient uptake, the root zone solution gets further out of balance with every pass. If this continues, eventually the root zone solution gets too far out of balance and the plants suffer.

It is vital to realise that the suggested feed formula in Table 3 is only a base from which to work. The important solution is the recommended root zone solution. The grower's aim is to maintain the root zone solution at this nutrient balance. In order to achieve this, the nutrient balance of the fertiliser input into the system has to equal the plant nutrient uptake. This requires regular analysis and calculation.

Interpretation of nutrient analysis and fertiliser calculations

These are topics for a full paper each and therefore beyond the scope of this paper. However, I have covered these topics several times in recent years.

References on nutrient analysis and management:

- "Commercial Hydroponics in Australasia" - PCA,
- Australian Hydroponic & Greenhouse Conference Proceedings 2003 - PCA,
- Australian Hydroponic & Greenhouse Conference Proceedings 2001 - PCA,
- HFF Conference Proceedings 2004 - HFF,
- "Hydroponic Q & A - Best of Readers Inquiries" - Casper Publications

References on fertiliser calculations:

- "Commercial Hydroponics in Australasia" - PCA,
- "Method for Calculating the Composition of Nutrient Solutions" - PCA
- "Hydroponic Q & A - Best of Readers Inquiries" - Casper Publications

Influence of raw water quality

Until now, I have only discussed nutrient ions which have been added as fertilisers. That is, the water has been taken to be reasonably pure. In the real world, this is often not the case and the quality of your water can have a major impact. Freedom from suspended matter and pathogens is an obvious requirement for a hydroponic water supply.

When considering dissolved solids there are two basic types, those which are nutrients and those which aren't. The nutrient ions which are in the water should be allowed for in your formulations if the amount is significant.

There are several traps to avoid. The iron content in water supplies is much more of a problem than a benefit because it oxidises quickly and so is of no use as a nutrient. Iron also helps cause dripper blockages and should be removed by aeration and settling or filtration. A problem in some countries, but rarely in Australia, is water with too high a boron content.

So-called hard waters, containing calcium and bicarbonate and perhaps magnesium are usually OK to use if these are the only significant dissolved solids. The bicarbonate will need to be neutralised by acid, which can be useful for buffering, but can become a problem if the level is too high.

Much more of a problem, especially in Australia, is a high level of sodium chloride. While chloride is a micronutrient, and perhaps sodium also, their required levels are less than 1 ppm. Individual crops have different degrees of tolerance to sodium chloride. A list of relative tolerances is given in Table 4.

Table 4. Sensitivity of plants to sodium chloride

very sensitive	sensitive	tolerant
bean	cucumber	tomato
anthurium	capsicum	spinach
cymbidium	egg plant	endive
	lettuce	carnation
	gerbera	chrysanthemum
	alstroemeria	gypsophila
	rose	freesia

Sodium chloride becomes a major problem when either the sodium and/or the chloride are present at higher levels than the plants can take up, and hence build up in the system. In practice the major problems occur within closed systems where the build up can continue until reaching toxic levels.

A guide to likely maximum levels in the root zone solution is as follows:

- Tomato - 200 ppm Na, 300 ppm Cl,
- Cucumber - 150 ppm Na, 230 ppm Cl,
- Lettuce - 100 ppm Na, 150 ppm Cl.

Levels getting high slowly could be controlled by bleeding (often done unintentionally). If too high then solution renewal is the short term answer. In this case the long term choice is between installing reverse osmosis (RO) equipment or accepting some reduction in yield and quality.

If planning to use reverse osmosis be aware that pre-treatment is usually essential to prolong the life of the membranes, which can otherwise be an expensive ongoing cost. Also, part of the input water passes through the membranes to emerge virtually pure, however all the salt in the input finishes in the drainage water which is correspondingly stronger.

Management strategy

Knowing what is happening within your system is a vital start for good management. Ignorance of conditions can lead to disaster.

The essential management techniques are based around a very simple procedure:

Sample

Sample regularly.

Preferably use daily sampling of both the input and, especially, the solution around the plant roots. In recirculating systems, the input will probably need to be made up from A and B concentrates. In media based systems the most consistent root zone solution sample is usually the run-off (drainage). Take a full day sample weekly or fortnightly for chemical analysis. Particularly if there are signs of nutritional problems take a plant tissue sample at the same time.

In media based systems measure the feed and run-off volumes and calculate the percent run-off.

If you have suitable equipment (scale or a water content meter for rockwool), measure the water content of the medium.

Analyse

Test all samples for pH and, especially, EC. Regularly get a full chemical analysis done on the input and especially the root zone solution. This could be tied to a leaf analysis.

In media based systems calculate the percentage run-off.

Record:

Write down all the results. Keep a diary including other useful information such as weather conditions, crop performance and symptoms, pests, diseases, and what actions were taken.

Remember that you also have a legal obligation to keep a chemical use log, listing considerable detail about every spray application made on your farm.

Take action:

Manage by watching for trends and adjusting gently to correct them. Try to avoid taking severe corrective action. By making changes 'softly, softly' you should largely avoid getting far enough away from standard to cause solution based problems.

In general plants perform better when growing under stable conditions. Therefore your aim should be to provide those conditions and try to avoid using strategies that change conditions more than necessary. Especially try to avoid having to take severe corrective action.

Summary

A good practical knowledge of the plant is essential. That is, its environmental and culture requirements and how to handle pests and diseases.

The plant root system needs to be supplied with:

- adequate water,
- adequate oxygen,
- adequate balanced nutrients,
- sufficient volume for the mature plant roots.

The vital solution to control is that around the plant root zone, which needs to be monitored regularly and provides the basis for solution management.

Manage by sampling, analysing and recording and then taking gentle appropriate action to keep conditions steady by correcting any adverse trends.