A few basics of leaf tissue analysis in hydroponic crops

Adequate nutritional control is difficult. Although there are several tools to control your plant's chemical environment – such as pH, EC and ORP – in the end the main interest we have is to control the composition of plant tissue and how this composition affects plant development and yields. One of our sharpest tools to achieve this is leaf tissue analysis which allows us to look at plant composition levels and figure out if anything is wrong with our plants. Today I want to talk about this powerful tool, why it is not so simple to use, how to use it and why it can be so important in helping you figure out what's wrong with your crops.

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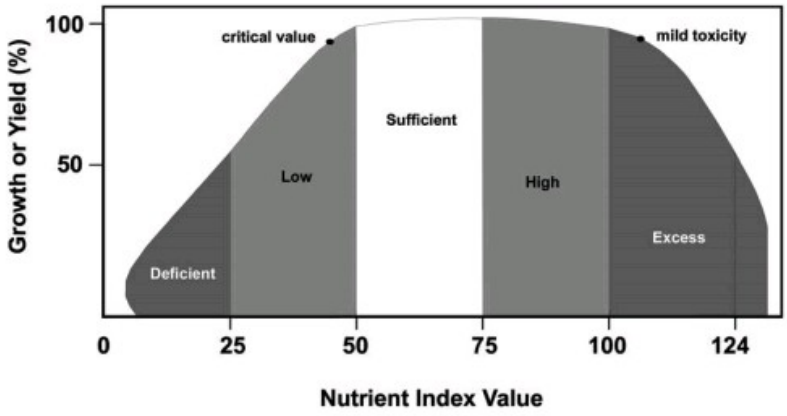

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The general model for nutrients and crop yields explains that plants will absorb nutrients till a point of maximum yield. After this point increasing nutrients will not increase or decrease yields substantially for a while but after a given point toxicity will prevail and plant yields will decrease due to nutrient toxicities and potentially osmotic pressure issues. This model is simplistic as it leads to an overall linear understanding of plant nutrients which is why

growers often find leaf tissue analysis puzzling and confusing.

In leaf tissue analysis we most commonly obtain a sample from the plant's most recent mature leaves. This tissue is analyzed by a lab and we obtain a chart where the percentage composition of the plant tissue for the different elements is given. We can then look at reference values for healthy plants and if any of our nutrients are outside this range then there is certainly something wrong with our crop's nutrition. Sometimes the lab will also give you some reference values but bear in mind that this aren't necessarily healthy plants but the average of what the lab gets for the plant specie you are growing. You either want an academic/government reference for healthy sufficiency ranges or you want to grow healthy plants yourself and take a reference sample to use for your future crops.

The tricky part is to interpret the tissue analysis. For example let's suppose that your tissue analysis comes up with low phosphorous. The immediate intuitive response that we get from the general model of nutrient sufficiency is that we should increase P in solution to get the P up within the leaves. However nutrient relationships are non-linear and in many cases what you have isn't a general lack of enough nutrient in solution but a problem getting that nutrient up to the leaves. In the case of P for example it might range from having excess chloride to having a nutrient solution that is too cold. I haven't seen a single case in hydroponics where low P in leaf tissue has actually been due to low P in the nutrient solution.

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Most Recent Mature Leaf — All Growth Stages

Macronutrients					
N	P	K	Ca	Mg	S
3.5–5.0%	0.30–0.65%	3.5–4.5 %	1.0–3.0%	0.35–1.0%	0.2–1.0%

Micronutrients					
Fe	Mn	Zn	Cu	B	Mo
50–300 ppm	25–200 ppm	18–80 ppm	5–35 ppm	30–75 ppm	0.1–1.0 ppm

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It is important then to realize that a problem within leaves is not necessarily a problem with concentration for that specific nutrient being too low or high in solution – in my experience it rarely is – but more so a problem with the balance of nutrients in solution or the environment that is causing a nutrient absorption issue. There are all sorts of antagonic and synergistic relationships between the different nutrients and the environment that will make this hard to interpret in many cases. To know what might be the cause first you will want to address all environmental issues that are known to cause toxicities/deficiencies and then look into addressing nutrient issues relative to the solution. You will want to pay a lot of attention to ratios instead of absolute concentrations.

You can have a perfectly good nutrient solution and the absorption problem might be related with something like transplant stress, root pathogens, incorrect carbon dioxide supplementation, light issues, temperature/humidity problems, etc. Growers tend to focus on the nutrient solution as the potential source and cure to all plant problems but the key is often in the environment and crop management more than within the actual nutrient solution. Even when the cause is the nutrient solution growers often misdiagnose the problem and increase or decrease nutrient concentrations, more often than not making the problem worse.

Due to the above it is not surprising that few hydroponic growers find tissue analysis very useful. While in soil crops

tissue analysis is usually used to manage fertilization and soil amendments in hydroponics the environment and solution are so controlled that the problems become much more difficult to diagnose and the solutions are often not what you would consider intuitive. It certainly requires a lot of reading and experience to properly interpret leaf tissue analysis and tackle the causal factors that are causing issues in hydroponic crops. However with enough experience or guidance leaf tissue analysis can be a great tool to know what your plant is taking, what it’s not and how these issues can be fixed.

Managing a Run To Waste (RTW) hydroponic crop from a nutritional perspective

Today it’s very common to create hydroponic crops using techniques where nutrient solution is not recycled. This type of crop, commonly called drain-to-waste (DTW) or run-to-waste (RTW) offers the advantage of having a very cheap setup – since no recirculation is used – with the big disadvantage that nutrient control becomes harder as there is no constant feedback of how the plants are affecting the nutrient solution. Today I want to talk about the main differences between a RTW crop and a recirculating crop and how nutrient management needs to be done in order to be effective in RTW setups.

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One of the most important difference between both crop types is the substrate. In a RTW crop you want the substrate to have a much higher capacity for water retention since you want to irrigate less frequently and ensure the plants are in contact with nutrient solution as much as possible without having aeration problems and a lot of run-off. Having a lot of run-off means wasting more nutrients in a RTW setup so you want to have a media that can minimize this. This means having a media like peat moss or coco coir where water retention can be very substantial.

The problem with the above is of course salt accumulation within the media. If you irrigate the plants with a full strength nutrient solution and you irrigate when the level of moisture descends then this is both because the plants have absorbed water and the solution has evaporated to some extent. This means that the next time you irrigate your total amount of salts will be the amount from your current irrigation plus the amount accumulated in the media. This can quickly turn into a very problematic situation where the plants are subjected to extremely high conductivity levels.

This is why run-off monitoring is key in RTW setups. You usually want to water your plants enough to allow for some run-off – usually 10-20% of the plant container's volume – so that you can perform measurements of pH and EC over that run-off. This is why it's so important to have the plants over

trays where run-off can be collected as measuring the run-off is very important to ensure that your plants are receiving adequate nutrition. Measuring the run-off of every plant is impractical so collecting the solution from many plants in a single tray and then measuring that output is a lot easier. Alternatively – if you cannot place the plants on trays – you can use a suction lysemeter to take out solution from a few plants after watering to monitor conditions around their root zone.

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In a RTW setup your run-off will always tend to be more concentrated than your input – this is normal – but you want to have conductivities in your run-off no more than 30% greater than your input concentration. If this is the case you should do plain water irrigation until your run-off has at least the same conductivity as your originally desired input. When you water with plain water also make sure you adjust the pH of the water to the value you desire. One of the lead causes of bad results in RTW setups is to have salinity build-ups that cause nutrient lock out simply due to a general lack of run-off monitoring. In general if watering using conductivities close to or above 2 mS/cm plain waterings should be done once for around each 1 or 2 nutrient solution feedings.

The pH is also very important. Depending on your media your pH can change substantially between your input and your run-off but in general you want your output pH to be as close to the desired pH as possible. You can compensate a bit by changing the pH of your input solution – for example if your run-off pH drops you can increase the pH of your input solution – but never increase your input pH above 6.5 or below 5.5. Some

media like peat can acidify solutions a lot with time, in these cases it’s very important to pretreat the media to avoid these problems with output pH. A strongly buffered input solution can also help in these cases. *Before starting your crop always test the run-off pH/EC of the media without plants to ensure you can make any needed treatments before you actually start your crop.*

The key to successful RTW setups from a nutritional perspective is run-off monitoring. Once you start monitoring your outputs you will see how your plants respond to your input solution and you’ll be able to better control the plants’ root zone environment. Of course these issues are all eliminated by recirculating setups since in that case the nutrient solution returns to the tank and there is a constant feedback of how the plants are affecting the solution. This can make recirculating setups much better at giving higher yields.

Using coco coir in hydroponics

Side by side with peat moss, coco coir is one of the most commonly used media in hydroponic culture. Its excellent root propagation and aeration properties, coupled with its adequate water retention, make it an ideal medium for hydroponic culture. Nonetheless, there are several issues that can arise when using coco coir, particularly due to its chemistry and variability. Today we are going to talk about using coco coir in hydroponics, what the main problems with coco can be and how these problems can be avoided.

TABLE 11.7 Levels of pH and EC in Coir

pH	EC ($mS\,cm^{-1}$)	Reference
4.9–6.4	0.17–2.32	Noguera et al. (2003b)
5.6–6.9	0.13–1.26	Evans et al. (1996)
4.8–6.8	0.32–0.97	Meerow (1994)
5.5–5.7	0.80–1.90	Handreck (1993)
5.0–5.7	0.12–1.51	Prasad (1997b)
4.9–6.6	0.32–0.41	Smith (1995)
6.0–6.7	0.2–0.4	Kipp et al. (2000) (coir dust)
5.9–6.1	0.2–0.9	Kipp et al. (2000) (coir chips)

Values of Noguera et al. (2003b), Evans et al. (1996), Meerow (1994) are based on saturated media extract, Smith (1995) on 1:5 water extract, and the others on 1:1.5 water extract. EC values have been converted to 1:1.5 water extract (see text).

EC and pH values for different coco coir sources

Coco coir is basically ground up dried palm tree husks. Although it is organic, it is much more fibrous than peat moss and for this reason, it does not suffer from some of the pH and decomposition issues commonly found with peat. Although coco is biodegradable, its decomposition can take more than 20 years, reason why it is a suitable media for hydroponics. It can even be used several times within a hydroponic crop in order to save production costs, as long as plant material is removed and the media is properly treated between crops.

Since coco coir comes from large plants grown across a variety of different conditions, the actual chemical makeup of the coco can change very substantially. The table above shows the pH and EC of different coco coir sources. As you can see, we have everything from an EC of 0.1 mS/cm to an EC of 0.9 msS/cm, with pH values that cover anything from 4.9 to 6.8. This is mainly due to the big variations in the ions contained within the coco and how these ions interact with the plant material.

Coco coir also has a high cation exchange capacity, meaning that it can retain large amounts of ions. These are only taken out if they are replaced by others with stronger affinity for the media or when strong interactions with chelating agents are possible. This is generally why coco is treated with calcium nitrate solutions, to remove many of these ions from the media structure and allow the media to be as neutral as possible when used in hydroponic culture. However, many coco

producers do not treat the media at all – or simply wash it with plain water – leaving a lot of potassium and sodium within the coco that needs to be accounted for. A lot of micro nutrients that are tightly bonded to cation exchange sites are often also often present inside the coir.

TABLE 11.9 Chemical Properties of Coir ($CaCl_2$/DTPA Extractable Macronutrients) ($mg L^{-1}$)

P	K	Ca	Mg	Na	Reference
–	183–222	100–172	36–58	85–92	Kipp et al. (2000) (coir dust)
–	47–98	56–60	31–79	30–78	Kipp et al. (2000) (coir chips)
8–17	304–720	6–15	8–28	110–114	Handreck (1993)
	69–128				Prasad (1997b)

TABLE 11.11 Chemical Properties of Coir ($CaCl_2$/DTPA Extractable Micronutrients) ($\mu g L^{-1}$)

Fe	Mn	B	Zn	Cu	Reference
	1100–1500	120–180	700–1300	170–2200	Handreck (1993)
79–157	814–1540	66–77	429–527	0–6	Kipp et al. (2000) coir dust
45–140	484–561	66–154	364–552	240–448	Kipp et al. (2000) coir chips
4100–7700	900–5000	200–400	500–1100	100–300	Prasad and Maher*

*Prasad and Maher unpublished data.

Some of the chemical properties of different coco coir sources

If you want to ensure your coco is as neutral as possible in terms of nutrients, you can extract it with a 1 g/L solution of calcium nitrate and then with 2g/L of tetrasodium EDTA. This will extract both macronutrients that are exchangeable for Calcium, and micro nutrients that can be extracted when using EDTA. The EDTA step is important, as coco can hold a large amount of micro nutrients within it, that can be exchanged and used by the plant. If you want your nutrients to all come from solution you will need to remove these contributions from the media. After this, you will then want to run plain water to remove any excess Ca and EDTA and then run your full strength nutrient solution for a few days. This will strip the coco from excess ions and equilibrate the cation exchange sites with your nutrient solution's composition.

Note that these steps aren't necessary to grow successfully with coco, but they can give the grower more control over the nutrients received by the plants. You can alternatively run

nutrient solution through the coco and then perform an analysis of the output, so that you can compensate for the nutrients that are given by the coco through the growth cycle. This of course means that you need to spend money doing solution analysis through the crop’s life to ensure that you’re adequately compensating for the coco’s contributions through the entire growing period.

When properly treated, coco can be a very good media for growing hydroponic crops. The larger aeration, better chemical stability and fibrous structure makes it better for root growth than most peat moss sources. Yields for several plants are also often larger or just as good in coco when compared with peat moss. The lack of important decomposition during growth cycles is also a big advantage over peat, as important drops in pH due to media decomposition can be avoided and the media can be more readily recycled.

Measuring ion concentrations in hydroponics using electronic tongues

One of the biggest problems in hydroponic research is the measuring of individual ion levels in hydroponic solutions. Right now there is no commercial solution for the accurate tracking of individual ions in hydroponic solutions and this makes it impossible to track ions in real-time to measure how nutrient absorption reacts to different environmental and chemical conditions. The only way to currently do this is to carry out more expensive and cumbersome ICPE analysis that provides a snap shot of a solution’s composition in time.

However there is a solution that might be coming up within the next few years which is the use of electronic tongues to measure the concentration of a large variety of ions in solution.

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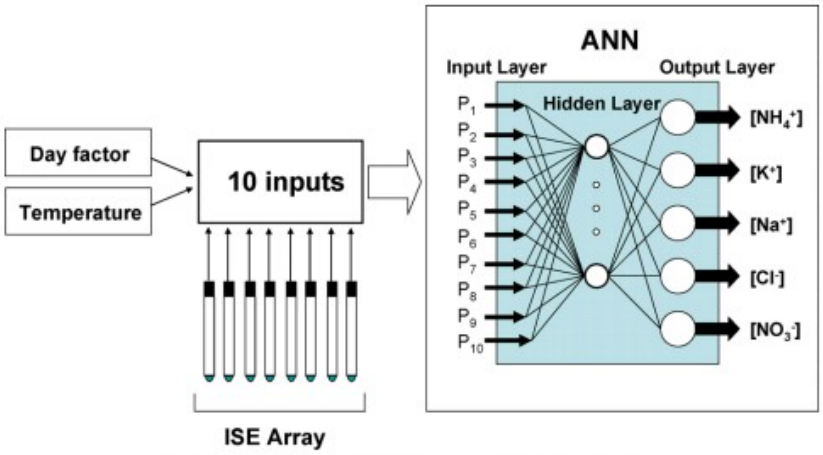

Fig. 2. Schematic representation of the electronic tongue approach.

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Many of you may be thinking, what about Ion Selective Electrodes (ISEs) ? These electrodes are designed to measure the concentration of individual ions in solution and they are perfect when you’re trying to measure a single ion against an unchanging background. The issue with ISE is that they work via the interaction of ions with molecules that have a especially strong interaction with them (what we can an ionophore) but the interaction can also be strong with other ions, generating interference. For example a K+ ion selective electrode usually uses an ionophore like vancomycin but this ionophore also has strong interactions with NH4+ (ammonium) ions. Since the concentration of ammonium also changes with time in hydroponics this means that your reading will be changed not only by how K+ concentration varies in solution but also by how NH4+ concentration changes.

In reality interference is not generated by a single ion but by a good portion of the ions present in a hydroponic

solution. This means that it is practically impossible to use an ISE in an accurate manner in hydroponics because you will always be getting changing interference from the other ions in solution. In the experiments I have done attempting to track nutrients using ISE this problem has always been so bad that the results become practically useless, regardless of how you calibrate the electrodes (since the concentration of the ions that interfere changes relative to the ion you want to monitor).

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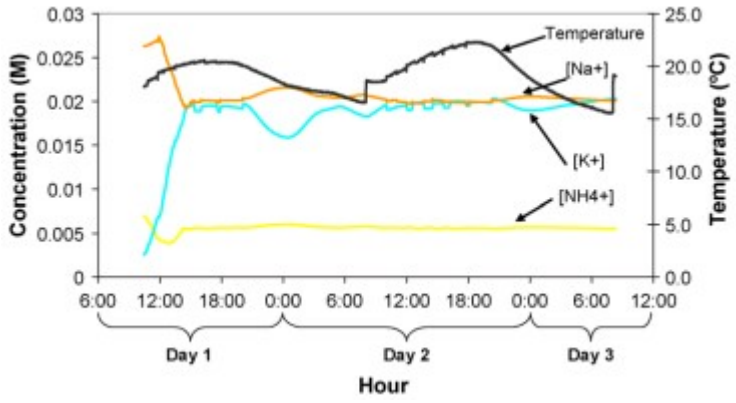

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Electronic tongues are an intelligent idea to circumvent these problems. The idea is to use many ISE for different ions – with many for the same ion and many generic ionophores that have poor selectivity – and then to use statistical modeling tools – mainly neural networks – to come up with ways to figure out the noise/signal/interference and get accurate measurements for ion concentrations regardless of what the actual readings of the electrodes are. The neural network is trained with data from solutions with varying concentrations of all the ions being monitored and this allows the creation of a robust prediction engine that can be used to get actual ion concentrations. M. del Valle's group in Barcelona has done some of the pioneering work in this area, the images in this post have been taken from some of their research papers on the subject (for example this one and this one).

Through this research they have been able to come up with ISE arrays that – using the neural network models – can measure concentrations in real-time for nitrate, chloride, sodium, potassium, ammonium, calcium, magnesium and phosphate. This means that you can effectively monitor how plants absorb different ions, not only allowing you to carry out experiments surrounding nutrient absorption but also allowing you to know which ions are getting depleted so that you can replace them. This brings a totally new dimension into hydroponic culture that simply isn't accessible right now.

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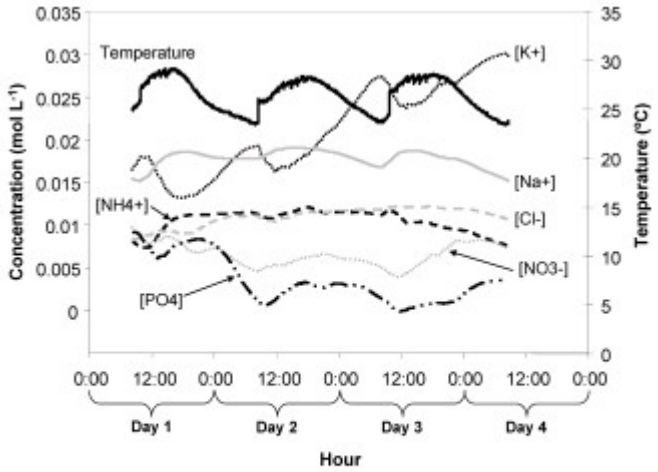

Figure 3. Representation of the concentration values predicted by the electronic tongue during the second application, in summertime, for the considered ions, ammonium, potassium, sodium, chloride, nitrate, and phosphate, in the nutrient solution during 3 days of continuous monitoring.

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It might take a significant time for these sensors to reach commercial applications – mainly due to the expensive calibration that is needed due to the variability in fabrication – so it might be years before we see something like this available to the general public. However if you have a commercial hydroponic setup that is large enough you definitely can follow this research to make your own ISE array and build an electronic tongue with them. This will give you access to a ton of information that is inaccessible to all of your competition.

Using Peat Moss in Hydroponic Culture

There are several different types of media available for hydroponic culture and from these peat moss is one of the most popular due to its low cost and high availability in some countries. This media is made up of decaying mosses and is used mainly in drop irrigation systems of both a recirculating and non-recirculating nature. However the organic nature of the media provides several important challenges to the hydroponic grower which – when not controlled – can lead to important problems associated with nutrient availability, inhibiting plant growth. Today we are going to talk about the characteristics of peat moss as well as how we can amend this media to make it suitable for hydroponic cultivation.

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TABLE 11.2 The von Post Scale for Assessing Degree of Decomposition of Peat (von Post, 1922)

Degree of decomposition (H)	Quality of water exuded	Proportion of peat exuded
1	Clear, colourless	None
2	Almost clear, yellow brown	None
3	Slightly turbid, brown	None
4	Turbid brown	None
5	Very turbid, contains a little peat in suspension	Very little
6	Muddy, much peat in suspension	One-third
7	Very muddy	One-half
8	Thick mud, little free water	Two-thirds
9	No free water	Almost all
10	No free water	All

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Peat’s main characteristic is its organic nature. Since it is made up of decaying organic matter this means that the chemical nature of the media will change depending on the degree of decomposition of the media and also depending on the

particular moss species that were used to produce the peat moss. You can know the degree of decomposition of a peat moss sample by using a simple procedure. Place a handful of wet peat in your hand and then squeeze it, the result – how the exuded water looks and whether peat is squeezed between your fingers – will tell you all about your peat. The von Post scale – developed in the 1920s – will then allow you to tell how decomposed your media is in a scale from H1 to H10.

Highly decomposed peat will tend to remain more chemically stable as the organic decomposition process has already been carried out. For this reason you want to buy what is commonly known as “black peat” (H7-H10) where microbial activity has already dialed down and the peat moss more closely approaches what we would call an “inert media”. This however does not mean that Peat moss is chemically inert at this point as it does contain as a significant amount of substances that can affect your nutrient solution.

One main characteristic of peat is that it’s acidic. This means that the pH of untreated peat will usually be between 3 and 4.5, too low for use in hydroponic applications. Peat is generally amended with calcium carbonate (lime) to make its pH go up and remain there but this process can be ineffective if the peat can still decompose very significantly (if you buy peat with decomposition < H7). This also contributes high amounts of Ca into the media which might lead to nutritional problems if Ca is also applied normally in solution. To alleviate these issues peat is also sometimes treated with lime/dolomite mixtures so that the counter-ions are both Mg and Ca. Alternatively – but more expensively – this problem can be solved by using phosphate buffer solutions that are run through the peat for a significant period of time. A potassium monobasic/dibasic phosphate buffer at a pH of 6.5 with a 100 mM concentration can buffer the peat moss. For this the buffer needs to be applied until the run-off pH out of the peat comes out unchanged. Then tap water should be applied to remove the

K/P from the media. Note that this will only work for black peat that's already gone through most of the decomposition process as lighter peats will simply decompose further and acidify the media again.

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TABLE 11.3 Cation Exchange Capacities of Different Peat Types (Puustjarvi and Robertson, 1975)

	Cation exchange capacity (CEC)	
Species or peat type	cmol kg^{-1}	meq L^{-1}
Undecomposed sphagnum moss peat	130	80
Sphagnum sedge peat	110	60
Sedge peat	80	40
Highly decomposed black peat	160	240

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However if all you can get is already treated peat moss then you should run nutrient solution through your peat for a while before putting your plants in to ensure that the peat's cation exchange capacity has already balanced with your nutrient solution's composition, this will also help remove nutrients applied to the peat that deviate the nutrient concentrations from what we want within the media. Peat can have a significant cation exchange capacity as showed in the table above – even more so for black peat – so a commercial source of peat may exchange a significant amount of nutrients with your solution. Peat is also not very good at retaining anions so the media will be unable to supply any N or P which will be leached very easily from the media. This inability to retain anions basically means that they will only be available when the plant is watered, reason why you should take care to correctly monitor moisture in your media to maximize your productivity.

For hydroponics it is therefore best to find untreated black peat and treat it yourself. If this is not possible then try to find unfertilized black peat – which has had only lime but no other nutrients added to it – and then use that. A great

characteristic of peat moss for hydroponics is that its nutritional content is low – allowing great control over the nutrients added through the composition of the nutrient solution – but this advantage is eliminated when the peat moss is filled up with fertilizers by companies that produce it for non-hydroponic purposes.

If you're using black peat also make sure to check how the peat behaves when watered, if the peat compacts too much you might want to add some perlite to your peat to increase the aeration of the media and prevent excessive compacting from happening. Add perlite until you get the desired balance between aeration and moisture retention. This is not necessary with all black peat sources but it can often be required.

Automated media moisture monitoring in hydroponic crops

> Irrigation control is one of the most important things to control in a hydroponic crop. Irrigate too frequently with a media that has high water retention and your plants will start to wilt as their roots die due to lack of oxygen and reductive conditions, water too sparingly and your plants will not grow as much as they could and maybe even die from the drought conditions you're imposing on them. On today's post we will discuss the topic of irrigation, more importantly how to know when to water your crops and how to control this process using sensor based approaches instead of just using look-and-feel to determine when to water your plants.

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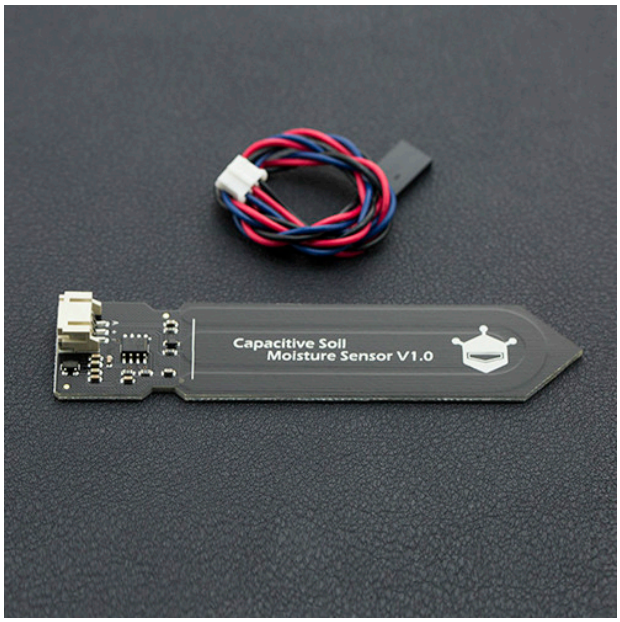

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Plant roots need to have access to water and nutrients. This means that the root zone needs to be saturated with nutrient-rich water as often as possible while avoiding oxygen depletion and salt accumulation. This means that irrigation needs to be controlled to ensure that plants get as much as possible, as often as possible, without going into any excess that would be detrimental to growth. Sadly there is no solution that is true for all crop setups and gauging irrigation frequency requires a close monitoring of what is going on within the crop.

To really know when to irrigate crops you should have a way to properly monitor moisture levels. This can be achieved through several methods, for example with tensiometers or with simple weighting of the plants, but many of these methods are often not cheap or practical for routine practice. Manual inspection of plants can also be misleading since top level moisture perception is subjective and can often lead to very suboptimal results.

In today’s world the best way to monitor moisture without

having to pay a high cost is to use simple capacitive moisture measuring sensors. These sensors are corrosion resistant and independent of salt concentrations in solution and therefore provide you with a good measure of moisture within your root zones without having to worry about the conductivity of the nutrient solutions. My favorites right now are this small capacitive sensor for smaller media containers and the chirp for larger containers. If you don't want the chirp features and just want sensor readings you can also get this simpler I2C sensor for larger containers. Both of these sensors are cheap and can be installed in crops with many plants.

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If you want to go with the simplest possible setup the chirp provides auditory signals when plants need to be watered, although this is not the ideal way to setup the sensors. Ideally you would want to connect these sensors to an arduino so that you can process the data. The arduino mega is particularly well suited for this task as you can connect up to 16 analogue input sensors to it, however you can use less analogue inputs with a normal arduino. Both sensors provide sample code for measuring values from an arduino, you can then output them to an LCD screen or save

them within a computer. You can even connect the arduino's digital outputs to a relay so that you can automatically trigger your irrigation system when a custom set moisture level is reached.

Obviously you do not have to place a sensor within each plant. Just monitoring around 10-20% of your crop will give you enough information to know exactly how moisture levels behave within your crop and when you should ideally water them. This will eliminate all the guessing from your watering and will allow you to water your media perfectly while completely accounting for how long it takes for water to leave your plants. This means you no longer would need to just guess when to water, but your watering will be perfectly tailored to what your media allows and what your plants need.

Hydrobuddy v1.60: A new update with important changes

During this past few weeks I have been working on modernizing Hydrobuddy in order to get it to compile with the latest versions of Lazarus and the Free Pascal Compiler (FPC) so that other people can more easily build the software from source. Today I want to talk about the latest release for Hydrobuddy (v1.6) that comes with some important changes that take the software a step forward and seek to make usage and building of the program much easier. If you're interested in downloading the source or binaries for the new version of Hydrobuddy please visit its official page here.

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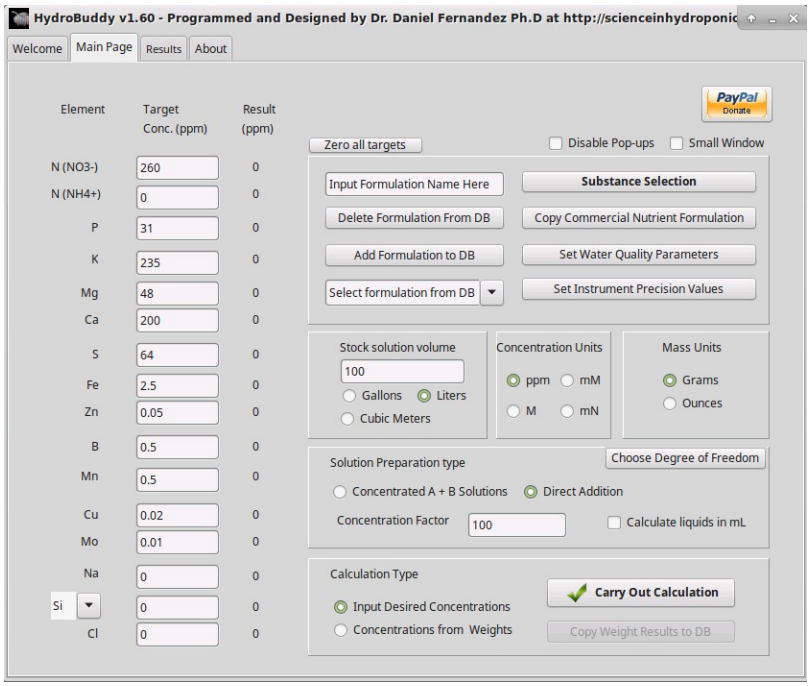

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I have decided to greatly simplify the program in order to remove sections and features that were complicated and really not used very often. This helped eliminate libraries that were previously required, some of which are no longer compatible with the latest version of the Lazarus IDE. I have therefore removed the program's ability to automatically update on startup and have also completely eliminated the data log section of the program. The elimination of the automatic updating makes the program much easier to compile as it eliminates some complicated requirements that were significantly difficult to install for those unfamiliar with the Lazarus RAD environment.

In addition to these changes I have also eliminated the Windows and Linux installers since these two made the overall setup and building process more complicated while they provided little additional benefit. The elimination of the installer means that the program can now be installed by simply extracting a zip file – how it was installed in the very beginning – something that makes it suitable for portable applications while before there might have been permission issues when attempting to run the installers on Windows/Linux.

In addition to the above I have also created separate versions of the program databases for Linux and Windows since these files are not compatible between operating systems and trying to build on Linux/MacOS – with the databases present that were Windows files – caused issues when testing the program. There are now suitable conditional headers that use the appropriate table files depending on the operating system being used.

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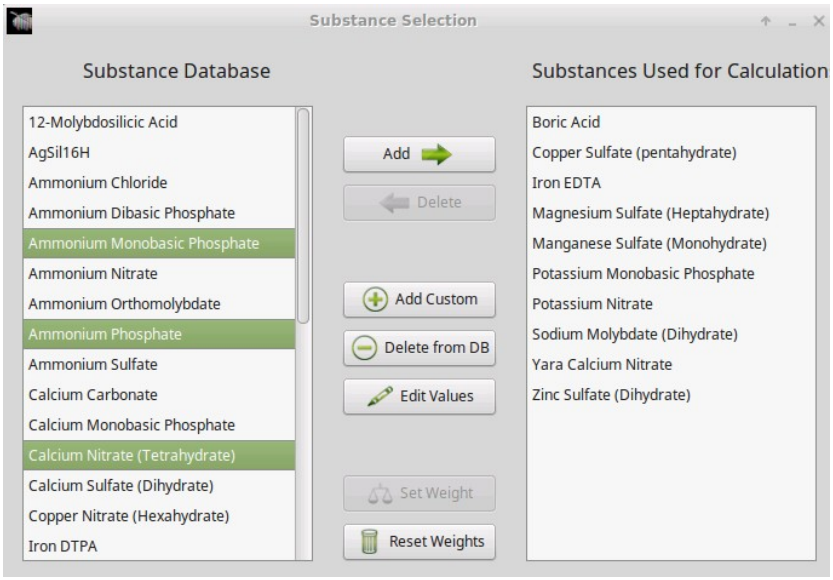

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I have also implemented a few additional features that improve some practical aspects when using the program. The substances used form now allows for multiple selects within the two substance columns so that you can perform multiple substance additions and deletions at the same time. This becomes very useful when you're changing your substance selections all the time since it allows you to easily add/delete multiple substances at the same time. In addition to this I have also implemented a "Zero all targets" button in the home page which basically sets all the ppm targets to zero. This can be very useful when you want to target particular single nutrients or you want to write targets from scratch.

Hydrobuddy's source is also now available via a [github]

repository to enhance the level of contributions from other programmers. This means that others can now checkout the source, modify it and contribute their own code changes to the program so that we can implement additional features or functionality.

Do you really need to be using RO water?

One of the most common practices in hydroponics is to use reverse osmosis (RO) water in order to create your hydroponic nutrient solutions. This water is made by running another water source – most commonly tap water – through a reverse osmosis system that removes a very large portion of the ions within the initial water source. The RO process is very energy intensive and also uses a large volume of water, only around one third of the water input ends up as RO water while the rest ends up as a more highly concentrated solution. Today we are going to discuss whether using RO makes the most sense, when it doesn't and how you can make sure that using tap water does not cause you any important issues.

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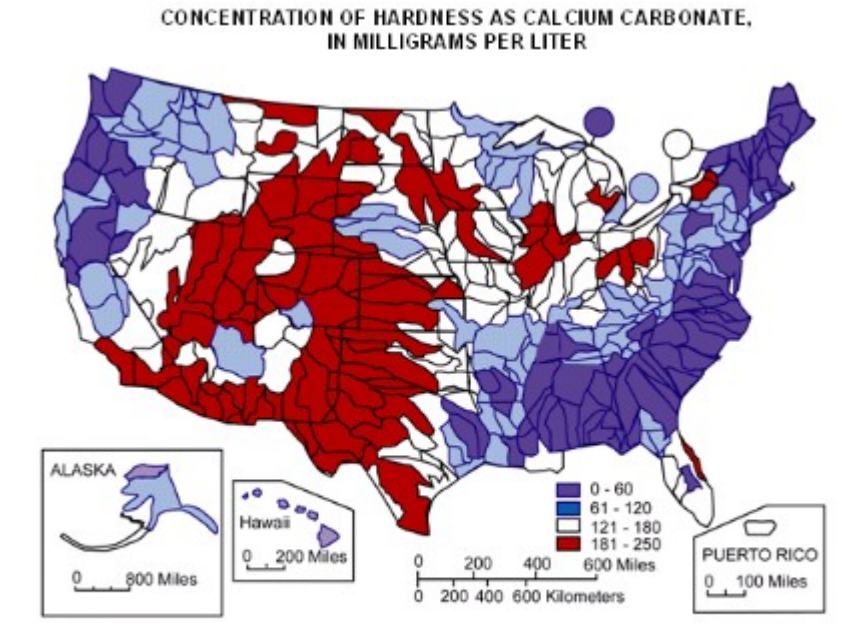

Mean hardness as calcium carbonate at NASQAN water-monitoring sites during 1975 water year.
Colors represent site data representing streamflow from the hydrologic-unit rea.
(Map edited by USEPA, 2005)

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The idea behind using RO water is to have the best “base” for the construction of a nutrient solution. If your water starts up with some substances within it then the amount of control you have over composition is limited and therefore your results might suffer because of that. If for example your nutrients add 150 ppm of Ca but your water already contains around 40-60 ppm then adding so much Ca might place you within a suboptimal spot. If your water contains a lot of carbonates, sodium, fluorides or other substances they can also cause significant problems within your hydroponic crop. Using RO water brings a “clean slate” that ensures that what you add is what you get.

So what is wrong with RO water? There are two main issues with using RO water. The first is that it’s a very energy intensive process – therefore a costly process – and the second is that the waste products of the RO process can create environmental problems. Additionally tap water already contains many nutrients necessary for plant life – mainly Mg and Ca – so why would you remove these elements only to later add them again later on? Surely you would rather save the energy from the RO

process and use the nutrients within your water as part of your nutrient solution.

The above map shows you the mean hardness of water (as ppm of calcium carbonate) across the United States. The people with the highest Ca concentrations have around 100ppm of Ca while those who have the least have around 0 to 24ppm. This means that for the people with the highest Ca, the Ca from tap water could contribute more than 50% of the Ca needed by a flowering crop while for the other states the contribution would be rather small. If your water is high in Ca then chances are it is also high in Mg so performing a water analysis will be necessary. From my experience with customers Mg is usually around one fourth to one third the concentration of Ca in solution, but the proportion can change significantly depending on the zip code. The table below shows the Ca/Mg content of water sources at different overall hardness levels in Germany.

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total hardness ppm as $CaCO_3$	calcium mg/l	magnesium mg/l	calcium hardness mEq/l	magnesium hardness mEq/l
25	7	1.8	0.4	0.2
50	14	3.6	0.7	0.3
75	21	5.5	1.1	0.5
100	28	7.3	1.4	0.6
150	42	10.9	2.1	0.9
200	56	14.6	2.8	1.2
300	84	21.9	4.2	1.8
400	112	29.2	5.6	2.4
500	140	36.5	7.0	3.0
600	168	43.7	8.4	3.6

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Mineral content in water also changes substantially as a function of temperature since rocks that contribute Ca/Mg carbonates will be more soluble during the warmer months of the year. It is therefore ideal to get two analysis, one during February – usually the coldest month – and another during August, the hottest month, to get a good idea of the

range of Ca/Mg concentrations that you will be getting in your tap water. This will allow you figure out how to adjust your nutrients as a function of the average temperature where you live.

Carbonates are also something you should worry about, if you have a high water hardness you might have more than 150ppm of carbonate within your nutrient solution. This is not ideal since carbonate ions can cause issues in your crop. To deal with this you can simply work at a slightly more acidic pH (say 5.6-5.8) this will limit the amount of hydrogen carbonate ions that can be present within the water as it will shift the equilibrium significantly more towards the evolution of carbon dioxide (since carbonic acid in solution is in constant equilibrium with atmospheric carbon dioxide).

There are however some circumstances where using RO water is unavoidable. If you water contains more sodium than your crop can deal with (read here for more info), more than 50 ppm of chlorides or if there are more than 10 ppm of fluoride then you will need to use RO water because those elements in those quantities are not going to be good for your plants. If these elements are absent or in low enough quantities then there is no reason why you would want to use RO instead of tap as using RO would be an unnecessary energetic and environmental expense given that you can just compensate for the ions already within your water through adjustments in your nutrient solution.

Hydroponic micro and macro nutrient sufficiency ranges

When you want to prepare a nutrient solution one of the first

things you want to know is which concentration ranges are appropriate for the growth of the specific plant specie you want to cultivate. You will definitely want to make sure that you do not feed either too much or too little of any of the essential nutrients a plant requires. Lucky for you there is a ton of research surrounding what we call “sufficiency ranges” in hydroponic culture. The sufficiency range of a nutrient is simply the range of concentration where a plant does not show a toxicity or a deficiency but develops in a normal manner. On this blog post we will talk about the different sufficiency ranges that are provided across the scientific literature and what they tell us about plant nutritional needs.

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Table 4.3. Target nutrient levels in NFT solution in ppm. (Beam et al. 1990, Ministry of Agriculture and Food, Ontario 1988)

pH		5.5	6.0	6.5
Conductivity (μS/cm)		1800	2000–2500	3500
		Minimum[a]	Optimum	Maximum
Nitrate nitrogen	(NO_3^--N)	50	150–200	300
Ammonium nitrogen	(NH_4^+-N)	5	10–15	20
Phosphorus	(P)	20	50	200
Potassium	(K)	100	300–500	800
Calcium	(Ca)	125	150–300	400
Magnesium	(Mg)	25	50	100
Iron	(Fe)	1.5	6	12
Magnesium	(Mn)	0.5	1	2.5
Copper	(Cu)	0.05	0.1	1
Zinc	(Zn)	0.05	0.5	2.5
Boron	(B)	0.1	0.3–0.5	1.5
Molybdenum	(Mo)	0.01	0.05	0.1
Sodium	(Na)	–	<30	<90
Chloride	(Cl)	–	<50	<150
Sulfur	(S)	–	50–200	–

[a]The concentrations listed as minimum are the approximate lower limit of a preferred range; in general, these minimum values are above those at which deficiency symptoms would develop

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The first thing to be clear about is that there is no single “sufficiency range” table. There have been many people who have worked on this subject using different plants and each one of them will tell you that the sufficiency range is slightly different. The above hydroponic nutrient concentration table shows you the minimum, optimal and maximum

nutrient values that were determined by the Canadian ministry of Food and Agriculture using NFT systems. These requirements were determined for flowering plants – mainly tomatoes – reason why you can see the optimum Ca range at 150-300 and the optimum K range at 300-500. Also notice the very high optimal Fe requirement of 6 ppm. This is almost certainly using either a form of unchelated Fe or an Fe chelate that is not so stable in the hydroponic conditions under study. The sufficiency range of micro-nutrients also depends on exactly what form of the micro nutrients you use since some forms are absorbed much more efficiently than others (it's not the same to have 3 ppm of simple Fe+2 or 3ppm of FeEDDHA).

In general you'll see that micro-nutrient sufficiency ranges have the most disparity between different sufficiency range tables. This is mainly because both the form of the micro nutrient and the specific cultivation media play a huge role in determining sufficient and toxic levels in hydroponic culture. For example a media like peat moss will contain a far greater amount of micro-nutrients than something like say, rockwool, so it is very important to account for media contributions when assessing micro-nutrient sufficiency ranges. While plants require so much macro nutrients that the sufficiency ranges are fairly coherent between different studies in the case of the micro nutrients the media choice itself could provide the entire requirement of a micro-nutrient through the plant's growth cycle.

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Table 4.4. Nutrient concentrations and chemicals for tomatoes in NFT

Element	Desirable concentration (ppm)	Chemicals
Nitrate nitrogen	150–200	KNO_3, NH_4NO_3, $Ca(NO_3)_2$
Ammonium nitrogen	0–20	NH_4NO_3, $(NH_4)_2$ SO_4
Potassium	300–500	KNO_3, K_2SO_4, KH_2PO_4
Phosphorus	50	KH_2PO_4, NaH_2PO_4, $CaHPO_4$
Calcium	150–300	$Ca(NO_3)_2$, $CaSO_4$, $CaHPO_4$
Magnesium	50	$MgSO_4$, $Mg(NO_3)_2$
Iron	3	FeEDTA, FeEDDHA
Manganese	1	$MnSO_4$
Copper	0.1	$CuSO_4$
Zinc	0.1	$ZnSO_4$
Boron	0.3–0.5	H_3BO_3
Molybdenum	0.05	$(NH_4)_6MO_7O_{24}$
Sodium	Maximum 250	
Chlorine	Maximum 200	

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The second image shows another sufficiency range table for hydroponic nutrients. This time we can see the source salts being used. As you can see we have a fairly good agreement in the macro-nutrients – with perhaps the exception of the ammonium minimum being set at zero – but in the case of the micros we see that the recommended amount of Fe is actually 3 ppm instead of the 6 ppm that were recommended before. This is most probably because in this case some percentage of this was given as FeEDDHA, which is much more effectively absorbed than either unchelated Fe sources or Fe EDTA. The boron range is exactly the same and this is undoubtedly because boron is always supplied in the same manner in hydroponic crops, therefore its sufficiency range tends to be coherent as long as the same plant specie is used for determination.

Macro nutrient suggestions are also not free from variations. Depending on the method used to determine the sufficiency range there can also be differences. The table below shows you yet another sufficiency range table which was geared towards maximum yields in terms of product weight. In this case You can see optimum K concentrations in the 50-200 range which is confusing given that the two tables before had suggested a much higher range of 300-500 ppm. Who is right here then? Do plants require 300-500 ppm of K for optimum growth or can they

do fine with 50-200?

TABLE 8.1 Ranges of the Essential Element Concentrations in Nutrient Solutions and Plant Tissues, and the Required Annual Amounts for Maximum Yields

Element	Chemical symbol	Form available to plants	Nutrient solution	Plant tissues	Annual consumption
Macroelements			$mg\ L^{-1}$	$g\ kg^{-1}$	$kg\ ha^{-1}\ y^{-1}$
Calcium	Ca	Ca^{+2}	40–200	2.0–9.4	10–200
Magnesium	Mg	Mg^{+2}	10–50	1.0–2.1	4–50
Nitrogen	N	NO_3^-, NH_4^+	50–200	10–56	50–300
Phosphorus	P	HPO_4^{-2}, $H_2PO_4^-$	5–50	1.2–5.0	5–50
Potassium	K	K^+	50–200	14–64	40–250
Sulfur	S	SO_4^{-2}	5–50	2.8–9.3	6–50
Micronutrients			$mg L^{-1}$	$\mu g\ g^{-1}$	$g\ ha^{-1}\ y^{-1}$
Boron	B	H_3BO_3, HBO_3^-	0.1–0.3	1.0–35	50–250
Copper	Cu	Cu^+, Cu^{+2}	0.001–0.01	2.3–7.0	33–230
Iron	Fe	Fe^{+3}, Fe^{+2}	0.5–3	53–550	100–4000
Manganese	Mn	Mn^{+2}	0.1–1.0	50–250	100–2000
Molybdenum	Mo	MoO_4^{-2}	0.01–0.1	1.0–2.0	15–30
Zinc	Zn	Zn^{+2}	0.01–0.1	10–100	50–500

The answer is that both can be right. Under some growing systems plants might require the solution to have more K because the setup might make K absorption harder while in other setups you might want to have lower K. This sort of contradiction surfaces constantly in hydroponic nutritional studies, simply because the variability in the subject of study (yields of a certain plant) will tend to vary very significantly depending on exactly which plant is grown and under which conditions. Just the plant and its development phase can make a huge difference in what has actually been found to work better.

Checkout for example the Israeli service recommendations for growing three different plants across their life cycle. You can see that the amount of nutrients they use can be different from what we have learned before. In this case their recommendations for all plants fall within the sufficiency ranges in the previous table but notice how for strawberry plants we use a potassium level that is at most 90 ppm while for tomatoes we go as high as 250 ppm within the fruit ripening stage. Also notice how in the case of sweet peppers the P can go as high as 150 ppm while for tomatoes we always stay within the 30-40 ppm range. If we had followed the previous recommendations we would have never considered

something like a 150 ppm of P to be an acceptable value for this element, since all of these sufficiency range studies point to the optimum P being 50 ppm. However a sweet pepper is not a tomato. In the same way that a house cat isn't a tiger.

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TABLE 8.2 Recommended Nutrient Solution Compositions Matched to the Growth Phase in Soilless Culture in Israel

Growth phase	N	P	K	Ca	Mg
			(mg L^{-1})		
Strawberry in greenhouse					
Transplanting	55–60	20–25	45–60	60–70	35–40
Anthesis and first fruit wave	70–85	20–25	70–90	100	45
Second fruit wave	80–85	25–30	80–90	100	45
Third fruit wave	80–85	25–30	80–90	100	45
Fourth fruit wave	55–60	20–25	55–60	80	35
Summer sweet pepper in greenhouse and net-house					
Transplanting to blooming	50–60	50–60	75–80		
Anthesis to fruit growth	80–100	80–100	100–120		
Fruit ripening and harvesting	100–120	100–120	140–160		
Fruit harvesting	130–150	130–150	180–200		
Fall-winter tomato					
Transplanting	80–90	30–40	120–140	180–220	40–50
Blooming and anthesis	120–150	30–40	180–220	230–250	40–50
Fruit ripening and harvesting	180–200	30–40	230–250	180–220	40–50
Fruit harvesting	120–150	30–40	180–220	180–220	40–50

Source: Israeli Extension Service Recommendations.

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So although sufficiency range tables are good to determine starting points, you should be well aware that these tables need to be considered in the context in which they were created. The plant used, the exact nutrient salts used and the growing system can all play significant roles that may cause two sufficiency studies to tell you very different things. In the end the best thing that can be done is to use the values for the plant that is taxonomically closest to the one you want to study in the system that resembles your system the most and then go from there to establish what the best values are in your particular case.

What is the effect of chloride in hydroponics?

I recently wrote a post about the effect of sodium ions in hydroponics and how it is important to keep an eye on sodium levels due to the potentially negative effects they can have on plants. However you may have noticed that sodium is never added alone into nutrient solutions and there is always a counter-ion that accompanies sodium, which is – more often than not – chloride. This ion is very special and it has some clear effects in hydroponic culture. Today we are going to be talking about chloride, how it can dramatically affect plants and why it does so in such a special way.

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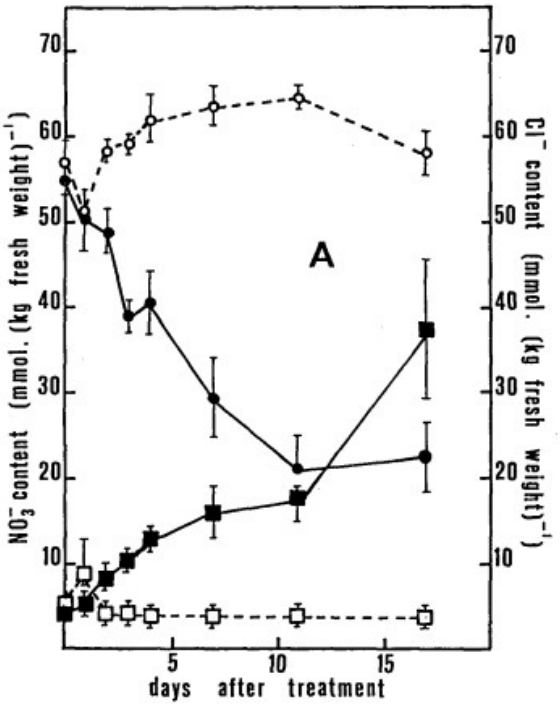

FIG. 3A: Effect of substituting chloride for ntirate in the nutrient solution on the nitrate content (●) and the chloride content (■) in leaf blades of lettuce plants, compared with the nitrate (○) and chloride content (□) of untreated plants. Light intensity: 65 W.m^{-2}, temperature 17°C and rel. humidity 70%. All values are averages of 3 determinations. Vertical bars indicate ± 1 SE of the mean.

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Chloride – not to be confused with chlorine – is a reduced form of the element Cl, an ion with negative charge (Cl-). Unlike elemental chlorine, which is a strong oxidant, chloride is extremely inert in terms of its chemical reactivity and does not appreciably react with anything in a hydroponic nutrient solution. This however does not mean that it is inert when you put it in contact with plants, as a matter of fact chloride is a micro-nutrient – essential for plant life – but it plays such a small role that any important increase in concentration can be detrimental. Usually there is no need to add chloride but simply the chloride present in the water – or as impurities within the other salts – will be more than enough.

But what effect does chloride have? Chloride is special in that it behaves chemically in a similar way to ammonium when in contact with plants, that is, chloride can go through plant cells very easily. This means that whatever chloride you put in solution is very readily absorbed, meaning that it counteracts the absorption of other anions very strongly. This is why the expected effect of plants dropping a solution's pH due to the addition of ammonium is completely negated if instead of ammonium sulfate you add ammonium chloride. This is because you add both an anion and a cation that are absorbed very fast, hence you do not affect the cation/anion absorption balance of the plant and the pH will continue to drop or increase in exactly the same manner as before.

This anion absorption of chloride implies that it readily competes with anion absorption. This means that if you have chloride and nitrate in solution plants will tend to absorb the chloride instead of the nitrate and you will see symptoms of nitrogen deficiency – not because you don't have enough in solution – but because nitrogen absorption is being hindered by the presence of a very competitive anion. Not only this but other anions, particularly phosphates, will also suffer and therefore you will also start seeing problems with P

absorption as well. If you're interested in reading more about this I recommend this chloride replacement study showing the dramatic effect it has on nutrient absorption.

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In many cases, deficiency problems in salinity studies can be attributed to the action of chloride and not so much the direct action of sodium ions. See here for a study that does a direct comparison on seedlings. However since sodium and chloride are very often present in equimolar ratios it is important to always search for both to know what type of problems you are dealing with. Chloride can cause problems at much lower concentrations than sodium, with just chloride concentrations above 20-30 ppm already causing very substantial issues for a wide variety of plants. If you have chloride it is wise to consider this when gauging the concentration of the other anions in solution as their concentration will need to be increased to account for the presence of this ion.

As in the case of sodium there is not much you can do to decrease the amount of this ion in solution since almost all chlorides are soluble. Some zeolites – like clinopitolite – might be able to remove some of these ions from solution but the most effective method if your water contains an important concentration of chloride is to use a reverse osmosis machine.

If this is not possible – due to costs or water availability – then the best chance you have is to try to increase anion concentrations to try to compensate for chloride absorption. However this will not work if the Cl concentration is very high as the osmotic pressure will be too high for the plants to handle after compensating.