Is my water source good for hydroponics?

Before starting your hydroponic project it is important to know whether your local water source can actually be used to water plants. Not all water sources are compatible with plants and some require special adaptations to the nutrient solution in order to become viable. In this post I will talk about the things that can make a water source unsuitable for hydroponics and the sort of modifications that would be required to make these water sources work with plants. The main points in the post are summarized in the diagram below.

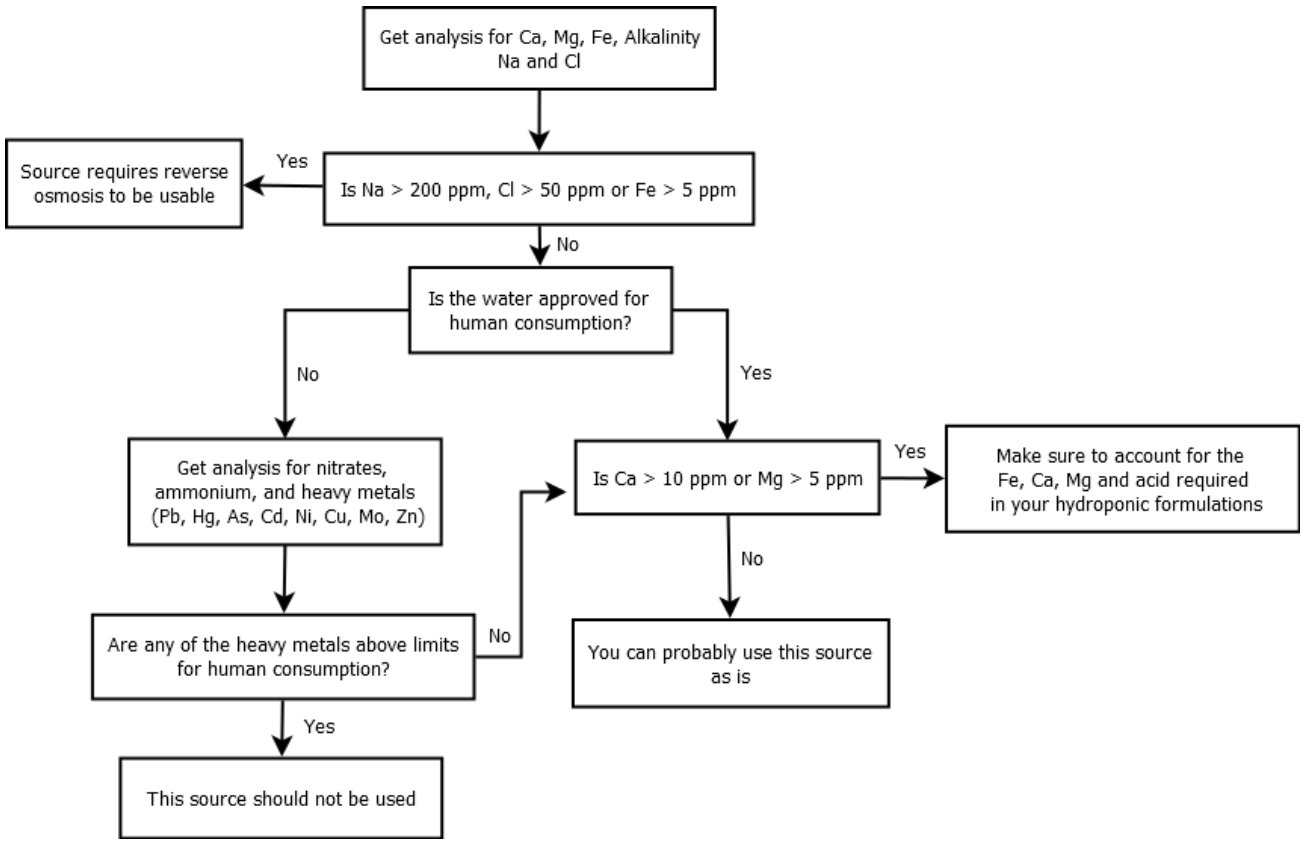


Diagram to figure out if your water can or cannot be used in hydroponics

Tap and well water sources can contain different substances characteristic of the natural environment where the water originated. Water that goes through rocky formations containing a lot of limestone will contain high amounts of

calcium and carbonates, while water that goes through dolomitic rock will contain significant amounts of magnesium as well. Water that contains high amounts of Ca or Mg is not necessarily problematic and can be dealt with by adapting the nutrient solution to account for these ions, you can read more about hard water and its use in hydroponics by reading my previous post on the subject. These water sources usually need a significant amount of acid to reach the 5.5-6.5 range, so accounting for the nutrient contribution of the acid in the nutrient formulation is also fundamental.

The most problematic water sources will contain high amounts of either sodium or chlorides, two ions that we cannot deal with easily in hydroponics and that can be specially bad for plants. You can read more about sodium in hydroponics here, and chlorides and hydroponics here. Sodium concentrations below 200 ppm can be manageable, but any higher concentrations will invariably lead to issues in hydroponics. Chlorides are even more harmful with the threshold for problems at just 50 ppm. Iron can be similarly problematic as sources that contain high amounts of Fe can be incompatible with plants and the Fe can be difficult to remove. This is why the first step in analyzing a water source should always be an analysis including Na, Cl and Fe. If the values are too high then this water source will require reverse osmosis to be usable.

If Na, Cl and Fe are within limits then we can ask the question of whether this water source is approved for human consumption. If it is then we know that the amounts of heavy metals within it should be low, as well as the amount of other ions, such as nitrate and ammonium. If the water has not been approved by a utility company for human consumption then we need to do heavy metal and nitrate/ammonium analysis to figure out if this is actually safe to use. In some cases well water sources can be perfectly fine to grow plants but the products might be contaminated with heavy metals that make them unsuitable for human consumption.

If a water source is within limits for all of the above then we should take into consideration whether we need custom formulations or whether we can get away with using commercially available hydroponic products “as is”. For sources that have relatively low amounts of Fe, Ca and Mg this is usually a possibility but for sources that have quantities of Fe above 2.5 ppm, Ca above 10 ppm or Mg above 5 ppm, it is advisable to go with a custom formulation that can account for the amount of minerals already present within the water. This can still mean using commercially prepared fertilizers only that the mixing ratios and schedules need to be adapted to manage what is already present in the water, so significant deviations from the manufacturer suggestions are to be expected.

Another important point is that none of the above accounts for potential biological activity within the water, which can be a big source of problems in plant culture. *For this reason always make sure to run the water through carbon filtration and have in-line UV filters to ensure that no bacteria, viruses or fungal spores get to your plants through your water source.*

A guide to different pH down options in hydroponics

The control of pH in hydroponic nutrient solutions is important. Plants will tend to increase the pH of solutions in most cases – as nitrate uptake tends to dominate over the uptake of other ions – so most growers will tend to use pH down much more than they use pH up. While most growers prefer to use concentrated strong acids, there are a wide variety of different choices available that can achieve different outcomes at different cost levels. In this post I want to talk about different pH down options in hydroponics, along with some of their advantages and disadvantages.

Hydrangeas change color as a response to different pH values in soil

The first group of pH down chemicals are strong acids. These are technically acids with very low pKa values, meaning they react instantly with water to generate at least one mole of hydronium for each mole of added acid. They offer the strongest ability to drop pH per unit of volume, which makes them more cost effective. However the fact that they often need to be diluted to make the pH addition process practical – because of how much the concentrated forms can change pH – can make their use more difficult than other forms of pH down. These are the most common options:

Phosphoric acid (from 20 to 85% pure): This acid doubles as a plant nutrient, meaning plants will be affected by the phosphorus added. It is commonly used in food – so food grade phosphoric acid can be bought cheaply – it also has additional deprotonations with strong buffering at a pH value of 7.2 with buffering capacity against bases getting stronger as the pH goes down all the way to 6.2. This is the most commonly used acid by hydroponic growers.

Sulfuric acid (from 20 to 98% pure): This acid is commonly used in car batteries and offers the largest pH dropping ability per unit of volume among all the strong acids. It is however important to use food grade sulfuric acid in hydroponics as normal battery acid can include some metallic impurities – from the fabrication process of sulfuric acid – that might negatively affect a hydroponic crop. Food grade sulfuric acid is safe to use in hydroponics. A big advantage is that plants are quite insensitive to sulfate ions – the nutrient provided by sulfuric acid – so adding sulfuric acid does not really affect the nutrient profile being fed to the plants. Note however that most battery acid products in developed countries are also ok, as the quality of these acids demands the metallic impurities (more commonly iron) to be quite low. If in doubt, you can do a lab test of the sulfuric acid to see if any impurities are present.

Nitric acid (from 30-72% pure): This acid also provides nitrate ions to plants, so it also contributes to a solution's nutrient profile. It is however more expensive than both phosphoric and sulfuric acids and more heavily regulated due to its potential use in the fabrication of explosives. The acid itself is also a strong oxidant, so storage and spillage problems are significantly worse than with phosphoric and sulfuric acid. Although this acid can be used in hydroponics, it is generally not used by most growers due to the above issues.

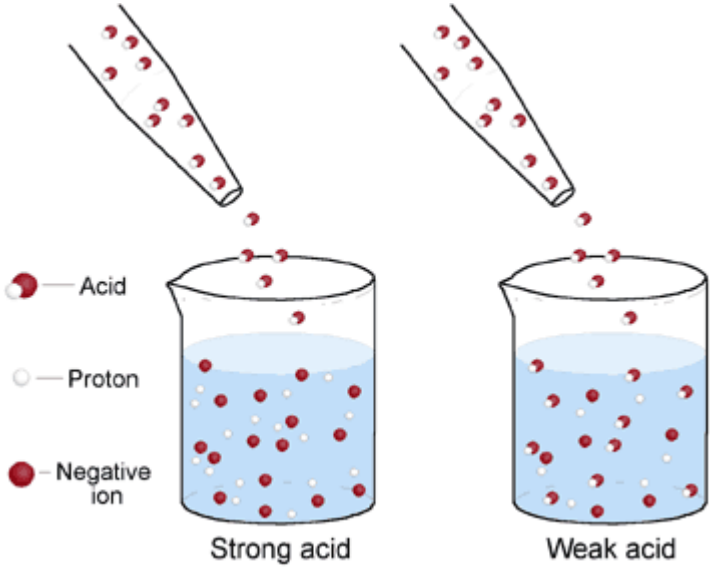


Diagram showing the dissociation of a strong vs a weak acid

The second group of pH down chemicals are weak acids. These are acids that do not generate at least one mole of hydronium ions per mole of acid when put in solution, but do provide a pH down effect as some hydronium ions are generated. This means that larger additions will be needed to cause the same effect but at the same time their handling is usually much safer than for strong acids. Here are some options that could be used as a pH down.

Common food grade organic acids (citric acid, acetic acid, etc): Organic acids are a very low cost way to lower the pH of a hydroponic solution as many of these are available off the shelf in super markets in food grade qualities. The main issue with organic acids – which anyone who has used them has probably experimented – is that the effect of the acids does not seem to hold (pH goes up quickly after the acid is added and the solution comes into contact with plants). This is actually caused by the fact that plants and microbes can actually use the conjugated bases of these ions nutritionally, causing an increase in pH when they do so. The initial addition of say, citric acid, will drop the pH – generating citrate ions in the process – these will then be absorbed by microbes and plants, increasing the pH again rapidly. *The use of these acids is therefore not recommended in hydroponics*.

Monopotassium phosphate (MKP): This salt contains the first conjugate base of phosphoric acid and is therefore way less acidic than it's full on acid partner. Since it's a solid its addition is way easier to control compared to the acid and it can also be handled safely with minimal precautions. It provides both potassium and phosphorous to a solution – both important nutrients – and therefore needs to be used carefully when used as a pH down agent (as it significantly affects the nutrient profile of the solution). Since it adds both a cation that helps counter pH increases by plants and phosphate species it provides a double buffering effect against future pH increases. It is a very common ingredients of commercial pH down solutions for this reason.

Monoammonium phosphate (MAP): Similar to the above, except for the fact that this salt adds nitrogen as ammonium, which is a nitrogen form plants are very sensitive to. Plants will uptake ammonium preferentially over any other cation, so MAP provides a very strong buffering effect against nitrate absorption, with potential problems if too much is used (although this depends on the plant species being grown). When MAP is used as a pH down its addition therefore needs to be carefully controlled in order to avoid excess usage. Due to the presence of this powerful ammonium buffer, MAP is generally very effective at preventing future increases in pH, although this might be at the expense of yields or quality depending on the crop.

Potassium bisulfate: This salt contains the first conjugate base of sulfuric acid and is therefore a powerful tool to decrease the pH of a solution. The resulting sulfate ions provide no chemical buffering effect, so the only buffering effect in terms of plant absorption comes from the addition of potassium ions, which can help mitigate nitrate absorption. This salt is also considerably expensive compared with the two above – which are commonly used fertilizers – and is therefore seldom used in hydroponics.

Which is the best pH down solution? It depends on the characteristics of the growing system. Generally a pH down solution needs to be easy to administer, cheap and provide some increase in buffering capacity overtime – to make additions less frequent – so the pH down product or combination of products that best fits this bill will depend on which of the above characteristics is more important for each particular user.

People who use drain-to-waste systems usually go for stronger acids, since they only adjust pH once before watering and then forget about the solution. This means that additional buffering capacity in the solution is probably not going to be very important and cost is likely the most important driving factor. If injectors are used then the strong acids are often diluted to the concentration that makes the most sense for them and most commonly either phosphoric or sulfuric acids are used.

For growers in recirculating systems options that adjust pH with some added buffering capacity are often preferred, because the same solution is constantly subjected to interactions with the plants. In this case it’s usually preferred to create a mixture of strong and weak buffering agents so that both quick decreases in pH and some increased protection from further increases can be given to the solution. In automated control systems using something like a concentrated MKP solution is preferable over any sort of solution containing phosphoric acid, as issues from control failures are less likely to be catastrophic.

Microgreen production at home: Getting the materials

Microgreens are plants that are harvested for consumption during the seedling stage, normally a week or two after a seed has been germinated. They can be one of the most nutritionally dense plant foods out there, given that they contain a lot of the nutrition already present in seeds plus phytonutrients derived from the beginning of the plant growing process (see here).

For these reasons and the fact that they can be grown in small amounts of space, all year round, I have decided to do a small home microgreen project in order to produce a relatively large amount of microgreens for home consumption. Since I have no experience creating setups of this type – I have worked in hydroponic forage productions but never microgreens for human consumption – I decided to look for the best possible setup and in the end decided to base this project on the setup described in this youtube video, following some of the advice given by this microgreen grower. *Note that I do not know if any of the financial claims in this video are true or even likely to be true, I just liked the growing setup configuration.*

I intend to produce microgreens like these

Using my own experience in hydroponics I then went for the materials that I thought best matched what was given in the video and ended up with the following list:

1. Styrofoam covers for trays (these you can definitely get cheaper, but these are the best compromise I could find on amazon, they are used in the dark phase of the germination process)
2. Rack to place the trays in (there might be cheaper ones but I needed something aesthetic as it will be visible in my apartment)
3. LED lights to use for growing (2 per rack section) (cool spectrum to limit etiolation, 2 tubes per rack space)
4. Trays (pizza dought box) . (note that this is polypropylene, not fiber glass, 5 trays fit in the rack)
5. Coco mats
6. Sprayer
7. Bamboo sticks used as separators in trays
8. Broccoli seeds (organic, untreated)

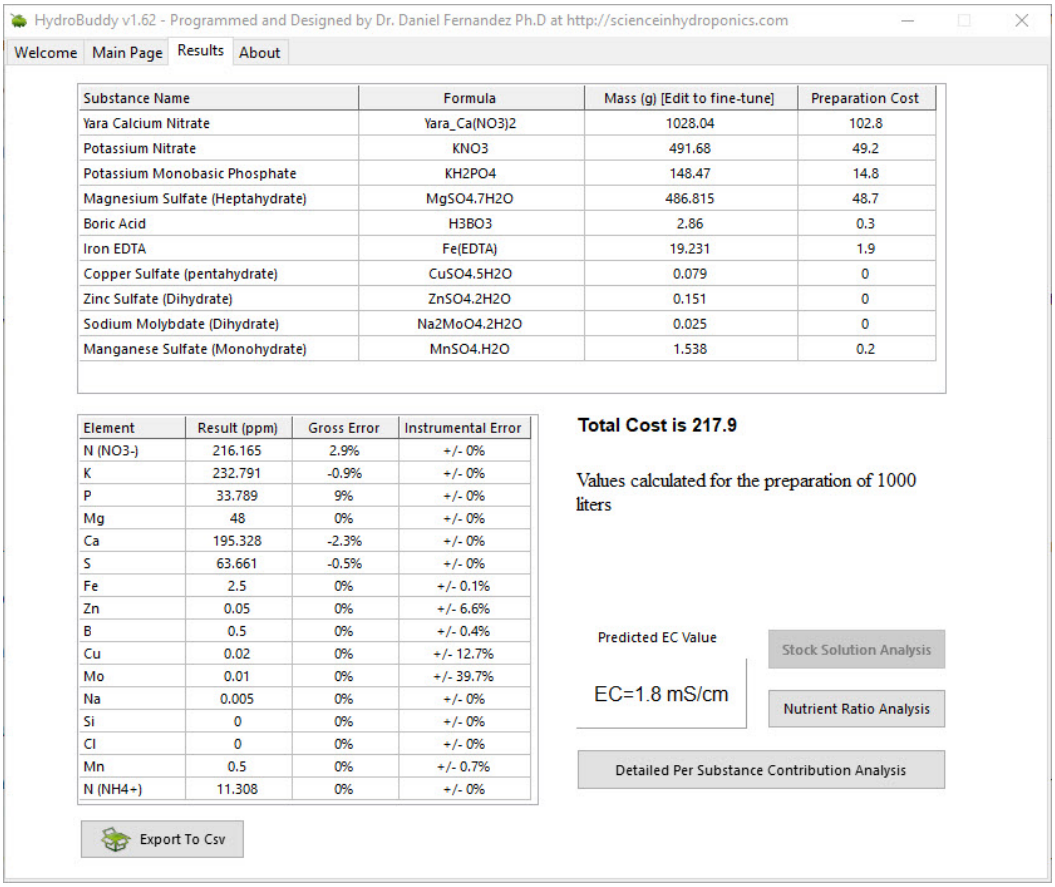
These are all the materials – besides water and hydrogen peroxide – that should be required to reproduce the basic setup I want to recreate. With this setup I will be able to grow 5 18×24″ racks at the same time, which is a lot of microgreens for home consumption. My plan is to experiment with broccoli seeds first – which are relatively cheap and easy to germinate – then move onto other plants that might be more expensive and difficult to germinate. Broccoli plants should germinate in 1-2 days and should be completely ready for eating in around 7 days. This can be a big difference compared with something like oregano which might take 6 days to germinate and then an additional 7-10 days to be ready for consumption. You can use a reference graph with the production times of different microgreens here.

I also have significant experience with enhancing germination, so this setup will provide me with the ideal conditions to test different germination treatments on the plants. Hopefully

I will be able to cover those in this blog. This project might also be the perfect opportunity to start a youtube channel so that you guys can experience the entire setup first-hand.

Nutrient solution conductivity estimates in Hydrobuddy

People who use Hydrobuddy can be confused by its conductivity estimates, especially because its values can often mismatch the readings of conductivity meters in real life. This confusion can stem from a lack of understanding of how these values are calculated and the approximations and assumptions that are made in the process. In this post I want to talk about theoretically calculating conductivity, what the meters read and why Hydrobuddy’s estimations can deviate from actual measurements.



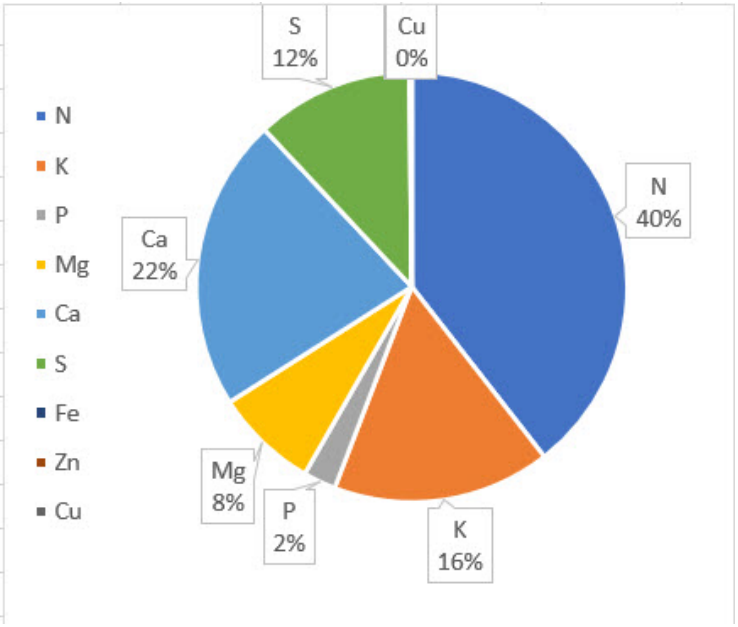
Standard Hoagland solution calculation using HydroBuddy with a set of basic chemicals.

The images above show the use of HydroBuddy for the calculation of a standard Hoagland solution for a 1000L reservoir. The Hoagland solution's recipe is expressed as a series of elemental concentrations, all of them in parts per million (ppm) units. The results show that the final conductivity of this solution should be 1.8 mS/cm but in reality the conductivity of a freshly prepared full strength Hoagland solution will be closed to 2.5mS/cm. You will notice that HydroBuddy failed to properly calculate this value by an important margin, missing the mark by almost 30%. But how does HydroBuddy calculate this value in the first place?

Conductivity cannot be calculated by using the amount of dissolved solids in terms of mass because charges are transported per ion and not per gram of substance. To perform a conductivity calculation we first need to convert our elemental values to molar quantities and then associate these values with the limiting molar conductivity of each ion,

because each ion can transport charge differently (you can find the values HydroBuddy uses in the table available in [this article](#)). This basically means we're finding out how many ions we have of each kind and multiplying that amount by the amount each ion can usually transport if it were by itself in solution. The sum is the first estimate in the calculation of conductivity.

	ppm	M	mS/cm
N	210	1.49E-02	1.06E+00
K	235	6.01E-03	4.42E-01
P	31	1.00E-03	6.61E-02
Mg	48	1.97E-03	2.09E-01
Ca	200	4.99E-03	5.94E-01
S	64	1.99E-03	3.18E-01
Fe	2.5	4.48E-05	4.84E-03
Zn	0.05	7.64E-07	8.07E-05
Cu	0.02	3.14E-07	3.37E-05
		Total	**2.70E+00**
		HB Guess	**1.8E+00**



Conductivity calculations carried out by HydroBuddy, also showing conductivity contributions per ion. This is done by converting ppm quantities to moles, then multiplying by limiting molar conductivity values here.

The image above shows the result of these calculations for an example with a perfectly prepared Hoagland solution. You can see that the estimate from limiting molar conductivity is initially 2.7 ms/cm – much closer to the expected 2.5 mS/cm – but then HydroBuddy makes an additional adjustment that lowers this down to 1.8 mS/cm. This is done because limiting molar conductivity values make the assumption of infinite dilution – what the ion conducts if it were all by itself in solution – but in reality the presence of other ions can decrease the actual conductivity things have in solution. HydroBuddy accounts for this very bluntly, by multiplying the result by 0.66, in effect assuming that the measured value of conductivity will be 66% of the value calculated from the

limiting molar conductivity values. This is of course wrong in many cases, because the reduction in activity due to the presence of other ions is not as strong. However it can also be correct in many cases, primarily depending on the substances that are used to prepare the formulations and the ratios between the different nutrients.

In my experience HydroBuddy tends to heavily underestimate the conductivity of solutions that receive most of their conductivity from nitrates, as this example, but it tends to do much better when there are large contributions from sulfate ions. When I first coded HydroBuddy all my experiments were being done with much more sulfate heavy solutions, so the correction parameter value I ended up using for the program ended up being a bad compromise for solutions that deviated significantly from this composition. With enough data it might be possible to come up with a more advanced solution to conductivity estimations in the future that can adjust for non-linear relationships in the conductivity and activity relationships of different ions in solution.

If your measured conductivity deviates from the conductivity calculated in HydroBuddy you should not worry about it, as HydroBuddy’s values is meant to be only a rough estimate to give you an idea of what the conductivity might be like but, because of its simplicity, cannot provide a more accurate value at the moment. The most important thing is to ensure that all the salts, weights and volumes were adequately measured in order to arrive at the desired solution.

Sugars in hydroponic nutrient solutions

Carbohydrates are an integral part of plants. They produce them from carbon dioxide, requiring no additional external carbon inputs for the process. However, since plants can absorb molecules through their leaves and roots, it is perhaps natural to wonder whether they could also get carbohydrates through the roots and avoid some of the stress they go through in order to produce these molecules from scratch. If plants can uptake sugar and we feed them sugars then will we get fruits with more sugars and bigger plants? It's an interesting question that I will try to answer within this post, looking at the potential use of simple sugars within hydroponic nutrient solutions.

Simple table sucrose

Although the above idea sounds straightforward, it hardly has any interest in the scientific literature or the commercial hydroponic industry. You will find no significant number of research papers studying the use of sugars – simple or complex – in hydroponic nutrient solutions and very few studies looking at sugar uptake and the interactions of *in-vitro* plant tissue with simple sugars. *This lack of interest and use is no accident, it comes from an already established understanding*

of plant physiology and the realization that it is not cost effective, useful or needed to add sugars to nutrient solutions.

Let us start with what we know about the subject. We know that plants exude very significant amount of sugars through their root systems and we also know that they can re-uptake some of these sugars through their roots (see here). From this paper it seems that maize plants could uptake up to 10% of the sugars they exude back into their root systems, which implies that some exogenous sugar application could find its way into plant roots. Even worse, transporting this sugar up to the shoots is extremely inefficient, with only 0.6% of the sugar making it up the plant. This tells us that most of the sugar is wasted in terms of plant usage, a large majority never makes it into the plant and the little amount that makes it actually never goes up the plant. *Plants are simply not built to transport sugars in this manner, they evolved to transport sugars down to roots and to fruits*.

But what about the roots? Given that the plant tissue that would be in direct contact with the sugar is the roots, it is logical to think about positive effects affecting them primarily. We have some studies about the influence of sugar solutions in seedlings (like this one) which does show that sugars can stimulate the growth of new root tissue in very small plants. However in large plants most of the sugar content in the roots will come from transport from the higher parts of the plant and the local sugar concentration will be low. Seedlings can likely benefit from sugars in the roots because leaves are producing very little at this time but larger plants are unlikely to benefit from this effect.

There is however one effect that sugars have that is very clear, they feed the rhizosphere around the plant's roots. Although plants try to care about this themselves – by exuding an important amount of sugars and organic acids – an exogenous sugar addition would most likely boost the amount of microbes

around plant roots (both good and bad ones). The profile of sugars and acids exuded by plants is most likely tuned by evolution to match the microbes that are most beneficial to it and an unintended and negative effect of sugars is to boost all microbe populations at the same time, regardless of whether they are good or bad for the plant. This also increases oxygen demand around roots – because aerobic microbes will want to oxidize these sugars – reducing the amount of oxygen available to plant roots. For this reason, any application of a sugar to a nutrient solution requires the inoculation of the desired microbes beforehand, to ensure no bad actors take hold. It also requires the use of a media with very high aeration, to prevent problems caused by oxygen deprivation.

Sadly there aren't any peer reviewed papers – at least that I could find – investigating the effect of exogenous sugars on the yields of any plant specie in a hydroponic environment. Given our understanding of plant physiology, any positive effects related with anecdotal use of sugars are most likely related with positive effects in the rhizosphere that are linked with improved production of substances that elicit plant growth in the root zone by favorable microbes. This is mainly because it is already well established that transport of sugars within plants from the roots to the shoots is incredibly inefficient, so any contribution of the roots to sugar uptake will be completely dwarfed by the actual production of sugars from carbon dioxide in the upper parts of the plant. It is not surprising that no one seems to want to do a peer reviewed study of a phenomenon whose outcome is already largely predictable from the accepted scientific literature.

If you're interested in the use of sugars in hydroponics, it is probably more fruitful to focus on microbe inoculations instead. Sugars themselves are bound to provide no benefit if they are not coupled with a proper microbe population and,

even then, you might actually have all the benefits without any sugar applications as the microbes can be selected and fed by plant root exudates themselves in mature plants although sugars might provide some benefits in jump starting these populations, particularly in younger plants. Also, bear in mind that there is also a very high risk of stimulating bad microbes with the use of sugars, especially if oxygenation is not very high.

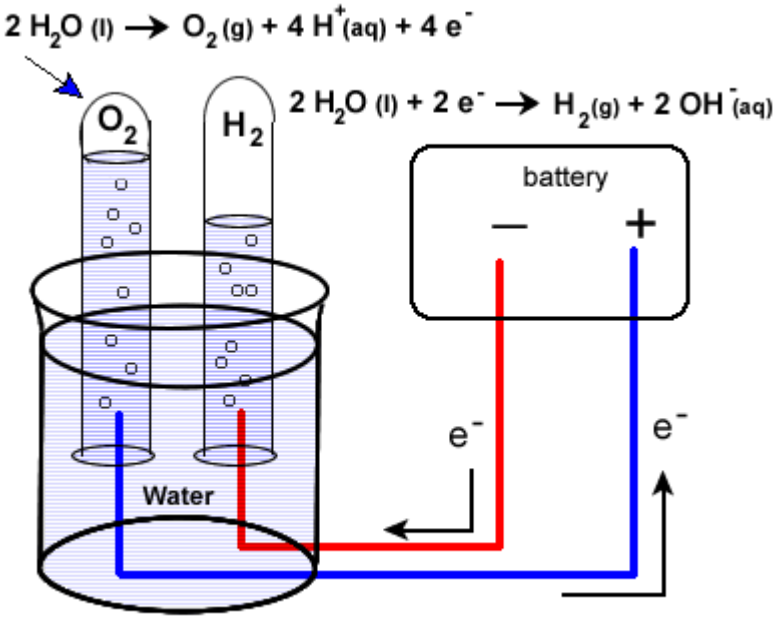
Controlling pH in hydroponics using only electricity

The ability of plants to assimilate nutrients changes as a function of pH. This makes maintaining the pH of nutrient solutions within an acceptable range – most commonly 5.8 to 6.2 – one of the most important tasks in a hydroponic crop. This is commonly done with the addition of strong acids or bases to decrease or increase the pH when it drifts away from the intended value. This requires either manual monitoring with careful addition of these substances or automated processes using pumps to ensure the pH always remains at the correct value. However both of these methods lack fine control, require a lot of maintenance and monitoring and can lead to costly mistakes. Today I want to discuss an alternative method that relies on a completely different idea to control pH, the idea that we can oxidize or reduce water using electricity to achieve changes in pH. **Yes, you can change pH using literally only electricity**.

A modern anion exchange membrane. Fundamental to the idea of an electricty-only pH control system

Let’s start by discussing pH and talking about how it is changes. The pH of a solution is calculated as -Log(|H^+|) where |H^+| is the molar concentration of H^+ ions in solution. In water, the dissociation constant 1×10^{-14} (at 25C), always needs to be respected, so we always know that the product of |H^+| and |OH^-| needs to give us this number. When you add acids you increase |H^+| conversely |OH^-| decreases and the pH goes down, when you add bases |OH-| increases, |H+| decreases and the pH goes up. *In simpler terms everything you need to decrease pH is a source of H^+ and everything you need to increase pH is a source of OH^-*.

This is where electrochemisty gives us the simplest solution we could hope for. Water can be oxidized or reduced. When you run a current through water – above the minimum required voltage – water splits into hydrogen and oxygen molecules. In the image below you can see how the water oxidation reaction generates H+ ions while the reaction on the right generates OH- ions. When you do this in a single cell – as shown below – the H+ ions generated at the anode react with the OH- ions generated at the cathode and the pH of the solution remains neutral while oxygen is produced at the anode and hydrogen is produced at the cathode.



The image above shows the half reactions involved in the oxidation (left) and reduction (right) of water.

However, we can take advantage of ion exchange membranes to separate these two processes, allowing us to control where each reaction happens and where the acid or base is generated (preventing them from just mixing and neutralizing). As a matter of fact, all we need is to have an electrode in our nutrient solution and another electrode in an auxiliary cell, separated from our nutrient solution by an ion exchange membrane. This concept is actually not new and was already proposed in a 1998 paper to control pH in hydroponic systems. Although it was never tried in a production system, all the concepts were validated and were shown to perform adequately in test solutions.

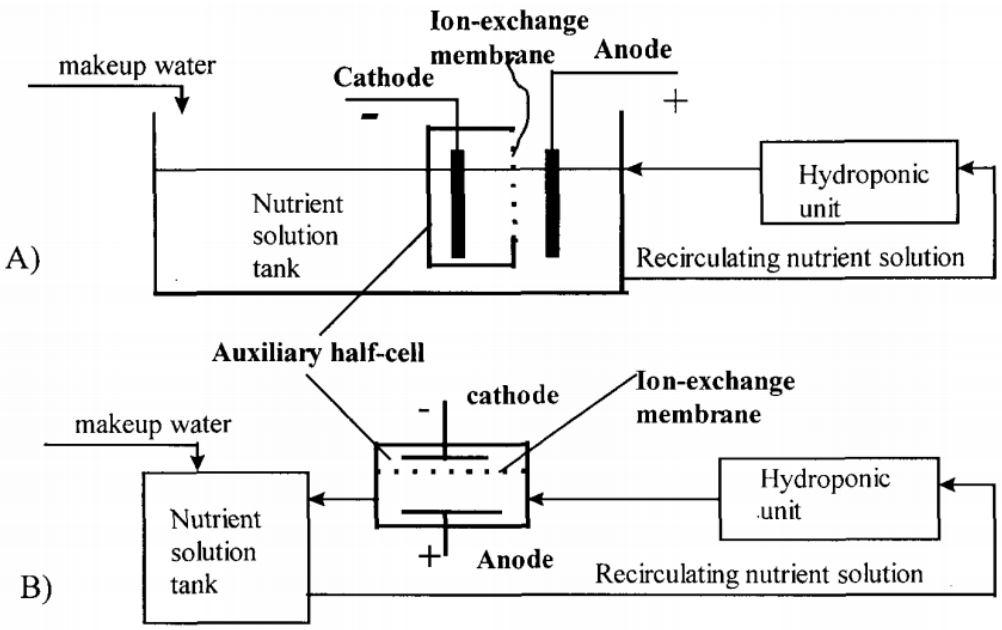


Image taken from [this paper](), which discussed the topic of electrochemical pH control in hydroponic systems at length.

One of the big challenges of this setup is that the cathode side involves hydrogen gas evolution – which could be dangerous – but can be completely avoided by replacing the cathode's half reaction with much more benign chemistry. As an example – also suggested in the paper above – you can replace the cathode half-cell with a copper sulfate solution with a copper electrode, with an anion exchange membrane. This would allow you to have your reduction reaction be the reduction of copper onto a copper place, which is a very tame reaction. Since the membrane only exchanges anions you would only have sulfate go to your nutrient solution, which is a benign anion in hydroponic culture. This of course means that your half-cell electrode and solution would need to be replaced with time, but this is completely independent from the control process (much more like refilling a tank of gas). The anode would only evolve oxygen in your nutrient solution, which is a potentially beneficial side effect.

Using a copper sulfate half-cell would however limit the control system to lower pH but this is not a problem since this is the most commonly used operation in hydroponics (very rarely do people have to increase the pH of their solutions).

If a proper venting system or catalytic recombination system is used on the cathode side you could also go with the simple water oxidation/reduction route and be able to increase or decrease the pH using basically, pure electricity.

I am definitely planning to build one of this setups in the future. Coupled with modern sensors and micro controllers this could make it extremely easy to maintain very fine control over the pH of the solution, compensating – in real time – all the changes in pH carried out by plants without the risk of heavily over or under compensating (as it happens when you use acid/base additions).

Maximizing essential oil yields: A look into nutrient concentrations

Essential oils are the main reason why several plant species are currently cultivated. These oils have a wide variety of uses either in the food industry or as precursors to more complex products in the chemical industry. Modifying nutrient solutions to maximize oil yields in hydroponic setups is therefore an important task. However, there are sadly no clear guidelines about how this can be achieved. In today’s post I wanted to create a small literature review of different research papers that have been published around the modification of nutrient solutions to maximize essential oil production and see if we can draw some conclusions that should apply to plants that produce them.

The variety of plants that produce essential oils is nothing but amazing. From plants where mainly the leaves are harvested – such as mint and basil – to plants where the flowers are used – such as roses – to plants where the seeds are used, like coriander. The wide variety of oil sources and plant species implies that the universe of potential research is immense, with every potential nutrient modification in every plant giving a potentially different optimal measurement. However, plants share some important characteristics – like photosynthesis and root absorption of nutrients – plus essential oils within different plants can share components produced using similar chemical pathways. For this reason, a look into the research universe of nutrient solution optimization for essential oil production is likely to serve as a base to guide us in the optimization of a solution for a particular plant.

Plant	Optimal (ppm)	Link to reference
Mint	195-225 N , 178-218 K	https://www.actahort.org/books/853/853_18.htm
Sweet Basil	180 Ca	https://www.cabdirect.org/cabdirect/abstract/20013048426
Costmary	200 N, 200 K	https://pubag.nal.usda.gov/catalog/732179
Mint	<= 276 K	http://www.scielo.br/scielo.php?pid=s0103-84782007000400006&script=sci_arttext
Chrysanthemum	159 Ca	https://pdfs.semanticscholar.org/13ea/999605458e65d9023dadbabca48464a5fa70.pdf
Chrysanthemum	43 N (NH4)	https://tinyurl.com/vqupwvf
Lavender	300 K	https://scielo.conicyt.cl/scielo.php?pid=S0718-95162017005000023&script=sci_arttext&tlng=en
Rose Geranium	207 K	http://ir.cut.ac.za/handle/11462/189

Rose Geranium	110 S, >= 68 P	https://www.tandfonline.com/doi/full/10.1080/02571862.2012.744108
Spearmint	200 N	https://www.sciencedirect.com/science/article/abs/pii/S2214786117300633
Lavender	200 N, 50 P	https://www.sciencedirect.com/science/article/abs/pii/S0926669015306567
Mint	414 K	https://sistemas.uft.edu.br/periodicos/index.php/JBB/article/view/601
Spearmint	50-70 P	https://www.sciencedirect.com/science/article/pii/S0308814618317862
Marjoram	>= 36 Mg	https://www.actahort.org/books/548/548_57.htm
Salvia	150 N	https://pubs.acs.org/doi/abs/10.1021/jf030308k
Dill	300 N	https://www.actahort.org/books/936/936_22.htm

Summary of different papers addressing essential oil yield optimization in hydroponic setups by varying one or several nutrient concentration values.

In the table above I summarize the research I found concerning the optimization of some mineral nutrient in the hydroponic production of a plant, specifically to maximize the essential oil yield. All of these studies optimized the nutrient within a given range and a >= or <= sign is used whenever the optimal value found is at the top or bottom of the range respectively. When more than one nutrient was optimized in the paper, I give you the values for both nutrients so that you can glimpse the optimal. Whenever the researchers suggest an optimal range instead of a value within their research this is also included as a range. I tried to find papers representing all macro nutrients but studies optimizing some elements were hard to find (Mg for example). Although I tried to include as many species as possible some species are just more commonly studied, as they are commercially more relevant (like mint and basil).

From these research results we can immediately see some clear trends. From all the studies there is no result where optimal total nitrogen concentration is below 150 ppm and 3 out of the 4 studies I found, agree that the optimal N concentration is at 200 ppm. In the case of K all studies agree that K should be at least 200 ppm, but I did find a study on mint that got a value of 414 ppm, far larger than the value found in other studies for the same specie. This is not an uncommon discrepancy in hydroponics – optimal yields being mixed in a wide range above 200 ppm of K – which can be caused by other

issues that can affect K absorption, such as the concentration of other important cations (like Ca and Mg) in the studies.

I was only able to find two studies that focused on Ca and both agree about optimal values between 150 and 180 ppm, although they address two completely different plant species (basil and chrysanthemum). In the case of Mg I found only one study and its conclusion was mainly that you want to have more than 36 ppm of Mg in solution. This is not surprising as Mg is rarely a growth limiting element in hydroponics and usually growth will not be limited to it unless its supply is very low compared to the supply of other nutrients (which is very rarely the case).

In the case of P, it’s not surprising that most papers that addressed this nutrient studied plants where the essential oils are mainly in the flowers (rose and lavender), as phosphorous is a nutrient commonly associated with flowering. In the case of rose the best value in the study was sadly the upper limit and in the case of lavender the optimal value reached was 50 ppm. In this case we can therefore probably only say that both studies share having an optimal result of >= 50 ppm but it’s hard to provide an upper bound for this. A study addressing P in spearmint also finds optimal P to be within exactly this range at 50-70 ppm.

Element	ppm
N	200
P	60
K	200
Ca	160
Mg	45

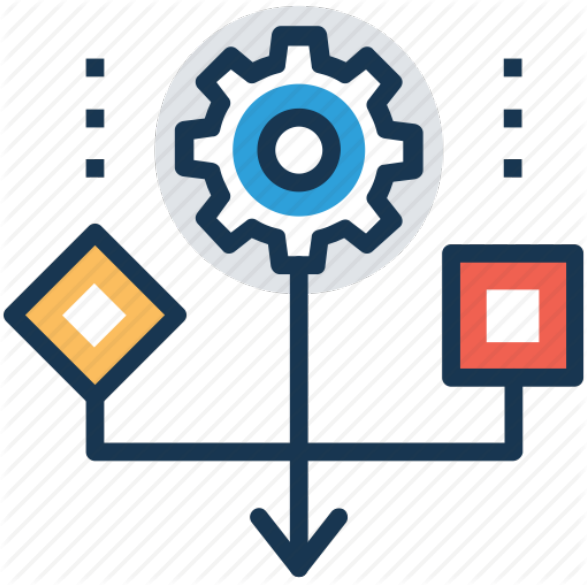
A base “guess’ formulation for a plant producing essential oils

With these results in mind, we can sketch a base solution for a plant where essential oil production is being targeted.. An

obvious guess would be to start with a solution with the concentration profile showed above. In this case we target N and K at 200 with an N:K ratio of 1 and we keep Ca at 160, making the K:Ca 1.25 (which is surprisingly close to the optimal value discussed in my Ca post). We leave P at 60 – the middle of the 50-70 range – and we keep Mg at 45, which is > 38 and is a value commonly used in regular hydroponic solutions. **The above will certainly not be the best solution for any single plant *a priori*, but it might provide a good base to start optimizing from if the objective is essential oil production.**

How to make your growing more systematic

The aim of every grower should be to improve their results with every new crop cycle. This is strongly facilitated by practices that make growing more systematic as problems become easier to spot and solutions become more obvious. However, having a systematic growing approach is not trivial as it requires a substantial amount of effort that might not pay off right away but across months or even years of implementation. In today's post I want to talk about what makes a growing process systematic and how you too can implement several techniques to improve and enhance your chances of producing better and better end products each year.



Systematic growing is all about information. How things are done might appear obvious when they are being done but as time passes the exact things that were done might be forgotten. For example if might be clear to you that at this moment you are doing three irrigation cycles per day of a certain volume per plant, but this might change in the future – perhaps you changed your irrigation at one point to adjust to higher temperatures – and the fact that irrigation was different is now lost in time. This happens all the time with all sorts of growing practices and it's especially exacerbated when there are rotations in personnel. A grower who learned anecdotally to do or avoid certain things might leave a company without that company ever knowing that those things were actually integral to the growing process. For this reason systematic growing is all about preserving and using all sorts of information. These are some of the actual steps you can take to make this a reality.

A specific person should be in charge of this. Keeping a proper record of all information and ensuring there is coherence in the on-going recording processes and the processes that are done – as you will read below – is a full-time job. A company that truly wants to be systematic in cultivation requires a single person to dedicate all their time to this. Trying to put this in charge of the people who

grow or the people who do administration is a mistake, since this is not a set of side-tasks, it is basically an entire full-time job.

Standard operating procedures should be a must. A standard operating procedure is a document that contains the steps you need to follow to perform a certain task in a crop. For example, the task of performing irrigation should be documented in a way that is always clear, up to date and that could be followed by someone who is completely new to the organization. The easiest place to start is usually to record a video of the person doing what they are doing, having them explain what is being done. At the very least this establishes a recorded process of what was done at a point in time and serves as a starting base to create a document. However keeping these things up-to-date and accessible is something that should be a top-priority.

Log as much sensor information as possible. Sensor readings are precious data that tells you a lot about the crop environment and what might be going right or wrong at each single point in time. Performing manual sensor readings and recordings is not a sustainable practice – as records can easily be lost and measurements can change depending on the person making them – so automated systems for the recording of all important sensor readings should be in place. A central database system that records all of this information is going to be key to the later access and easy use of this information.

Create expectations and see if they are met. When the two points above are put together you suddenly have a way to create expectations from procedures and then evaluate – using your sensor data – whether things that were supposed to happen actually did happen. I have seen several cases in crops when an important piece of equipment – a humidifier on a timer for example – fails to perform and there is really no awareness about anything being wrong up until there were real

consequences and plant losses due to the problem. Procedures establish expectations that mean certain things should happen in the real world and having the sensors to monitor whether those things are happening or not is extremely important. These readings can also be monitored in real-time when things are working normally and the expectation can be programmed so that users are alerted when something that should be happening is actually not happening.

Log all information about crop cycles and plants. Growers will often fail to log information that relates to crop cycles and plants in a way that is systematic. It is important to log which varieties of plants are grown, where they were exactly and what the results for each one of these different plant varieties were at the end of the crop cycle. People who do this generally have an ability to distinguish varieties that work better in their growing setup, which can be a huge boost for selection and productivity.

Schedule and log lab tests every crop cycle. Lab tests for leaf tissue and media are not only important when things are going bad but they are very important when things are going right because they create an important baseline to measure against. A company that never performs tissue analysis will have a harder time figuring out why things are not working as expected if they don’t have some expectation of how things should work out when everything is working as normal. Testing leaves and media every crop cycle – even at different stages – offers growers the ability to establish a baseline, catch problems early and fix problems more quickly if they appear.

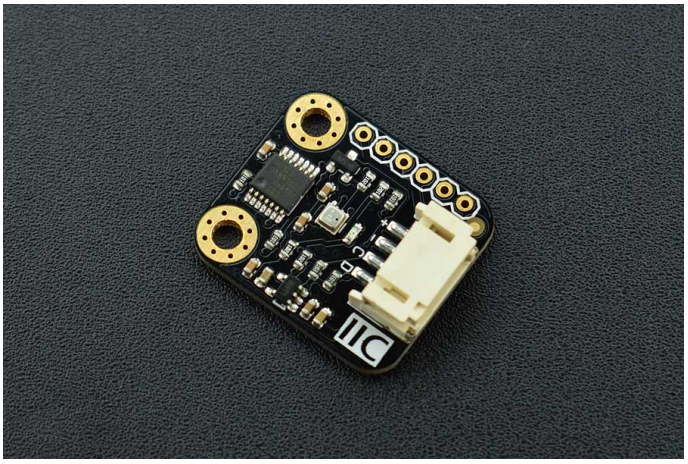
Have an environment for testing changes. A big and common mistake is to try to enact changes in a crop without previously testing the effect in a more controlled environment. Big changes carry big risks so it is important to test these changes in small testing setups before trying to bring them to a large growing operation. When testing changes it is also important to control the amount of variance that

will be introduced into the crop since introducing a large amount of changes at once can lead to an inability to say what the problem was if anything at all goes wrong.

A company that complies with all the above will be on its way to fast improvements and fewer problems. A business with a single person dedicated to ensuring all the operating procedures exist and are up to date, all sensor and plant data is recorded properly, all tissue tests are logged and scheduled and all sensor readings are acting within expectations according to the procedures will have a huge advantage over a company that does not handle itself systematically.

The best cheap sensor setup for relative humidity in hydroponic automation projects

I have written in the past about humidity in hydroponics, especially how accurately measuring humidity is hard due to problems with the sensors. In my experience during the past 5 years with different humidity sensors in Arduino based automation projects I have tried different chipsets and have now reached a conclusion about my preferred chipset setup for the measurement of humidity in hydroponics. Today I want to share with you my experience with different sensors, what I think the best overall setup is and where you can buy breakout boards that use these chipsets to use them in your projects.



One of my favorite sensors for the measurement of relative humidity in hydroponics

The first sensors I ever tried for measuring humidity in hydroponics where the DHT11 sensors which are the cheapest but have really poor accuracyand limited range. I then moved to the DHT22 sensors (also known as AM2302 sensors) which in theory have an accuracy of +/-3% but I had a lot of problems with the sensors dying on me as a function time, this was particularly the case when the sensors were places near plant canopy, where they could be exposed to much higher levels of humidity than those placed to measure overall room humidity values. We also tried using them in a commercial tomato greenhouse and the sensors placed near canopy failed miserably after only a couple of months. More infuriatingly, the sensors that did not outright die seem to have lost a lot of their sensibility, with increased hysteresis in their measurements as humidity changed through the days.

Manufacturers' Specification						
	AM2302	AM2320/AM2321	SHT71	HTU21D	Si7021	BME280
Operating Range	0–100	0–100	0–100	0–100	0–100	0–100
Absolute accuracy (%RH, 25°C)	±3% (10-90%) ±5% (<10, >90%)	±3% (10-90%) ±5% (<10, >90%)	±3% (20-80%) ±5% (<20, >80%)	±3% (20-80%) ±5% (<20, >80%)	±3% (0-80%) ±5% (>80%)	±3% (20-80%)
Repeatability (%)	±0.3	±0.1	±0.1	-	±0.025	-
Long term stability (% per year)	0.5	0.5	0.5	0.5	0.25	0.5
1/e Response (sec)	5	5	8	5	18 (with cover) 17 (without)	1
Voltage supply (V)	3.3–5.5	3.1–5.5(AM2320) 2.6–5.5(AM2321)	2.4–5.5	1.5–3.6	1.9–3.6	1.71–3.6

This table of properties was taken from this website.

I then moved to the SHT1x humidity sensors – which were much better and more reliable – and these sensors became my go-to sensors for around a year. However I was increasingly

concerned about problems with systematic errors, since all these sensors use a capacitive technique to measure relative humidity, so I decided to try other sensors that used different measuring methods. The only cheap sensor I could find using an alternative measuring technique was the BME280 – released within the last two years – which turned out to be a very reliable sensor. My default setup for measuring humidity has now become a 2 sensor setup where I connect one SHT1x and one BME280 sensor board to an Arduino and then make sure both sensors are within 2% to take a value or issue a control action. If the deviation between both sensors is above 2% then I make sure to be notified about it so that I can see if there is any problem with either of them. I was happy to learn that my conclusions are also supported by other people who have systematically evaluated humidity sensors.

Although I usually prefer the sensors from dfrobot for regular builds, as they are easier to use, you can find breakout boards or more elaborately packaged sensors with these chipsets at other places. In particular I have found the mesh protected SHT-10 sensor from Adafruit to be particularly useful for more demanding environments (like canopy, greenhouses or just outdoor sensing) which might be suitable for those of you looking for a significantly more robust solution to measure humidity, even if at a higher price. Adafruit also carries low cost breakout boards for the BME280 and the SHT-31D, which is a more accurate chip of the SHT family. In any case, I wouldn't bother with the AM family of sensors, as they have proven to be less reliable than the above mentioned counterparts.

Last but not least, please make sure to contact me if you're interested in getting my help or input to build a custom made sensing setup for your hydroponic facilities. Having wireless sensing and controls, all integrated into a centralized sensing unit, is perhaps one of the best ways to get reliable real-time data and enhance the control and decision making

processes within your hydroponic facility.

The media exchange solution test: A better measurement of media effects in hydroponics

In the traditional hydroponic paradigm we want media to be as chemically inert as possible. The ideal media in this view would absorb no nutrients, give off no nutrients and would not decompose or react with the nutrient solution in any way. However none of the commonly available media sources comply with these properties, reason why we must be vigilant and properly adjust the media we use to fit the needs of our hydroponic setup. In this article I am going to talk about the idea of using a direct comparison test of the nutrient solution against the media, to understand the effect the media will have when exposed to the target nutrients and how this can help us adjust our solutions to better play with the selected growing medium.

Different types of growing media

First, let us understand how the media interacts with a hydroponic solution. The media can do all of the following things:

- **Dissolve into the solution** (this is what happens if your media is something like sand or limestone). In this case the media is chemically reacting with the nutrient solution, therefore media is being irreversibly lost in the process. This can happen very fast, with something like limestone, or very slowly, with something like sand.
- **React and take something away from the solution**. In this case the media can use ions within the solution to perform reactions that create new substances that are insoluble. For example if you have media containing large amounts of rock phosphate this phosphate can cause the precipitation of heavy metal phosphates.
- **Release ions in exchangeable locations into the media.** This is different than dissolving because the media is not getting destroyed in the process but it is emptying "storage sites" that contain some ions that prefer the solution instead of these sites. This process is fundamentally reversible and – under the proper conditions – these sites could be replenished with the

same or different ions.

- **Take ions into exchangeable locations in the media.** This is the opposite of the process above. In this case the media will receive some ions into “storage sites” because these ions prefer the media to the hydroponic solution. The solution will therefore be depleted of these ions because they are being stored within the media.

Of most interest to us are the third and fourth points above, this is generally understood as the “exchange capacity” of the media. This determines how many and which nutrients the media can store. Different media can have storage sites with different affinities and in hydroponic setups we generally want to aim for the minimum energy state of these storage sites as they relate to our nutrient solution. Media that is already in equilibrium with the nutrient solution will tend not to change it while media that is far away from equilibrium with the solution will change it strongly towards the equilibrium point.

Think about coco coir, a commonly used media in hydroponics that can have a wide variety of different ion exchange capacity values and a lot of different ions initially in its “storage sites” due to the differences in sourcing materials and treatments done by different companies. Coco coir initially contains high amounts of potassium and sodium ions, but some companies treat it with Ca nitrate, which changes all these “storage sites” to contain Ca instead. These two sources of coco would interact very differently with our nutrient solution. In the first case the coir would exchange a lot of its potassium for Ca and Mg ions in solution – because these ions have higher affinity for the “storage sites” – while in the second case a little Ca would be exchanged for other ions (because all ions are in equilibrium with all the storage sites). The changes to the solution are very different and totally different approaches in nutrient composition changes

are required.

Traditional soil tests could provide some answer to us, they would definitely show the ions that could be exchanged to be different in both cases. But they tell us little about the equilibrium position of the media against our target nutrient solution. To make things more realistic we can actually do a test where we pass our actual nutrient solution through a column of media that is exactly what we're going to run it through in real life (with no plants of course). We then collect the input and output solution and run lab analysis of both of these solutions. **We can then compare the results and see how much the media is actually changing the composition of our input solution and we can then make some decision to adjust.** Such a test would proceed as follows:

1. Prepare the strongest final solution that will be used in the growing process. (for example the solution that is used at the peak of fruit generation in a tomato crop)
2. Take a sample of this starting solution to send for chemical analysis.
3. Pack a burette with a column of media as high as the containers the plants will be in.
4. Fill the burette with the nutrient solution.
5. Run as much solution as required to collect a sample of equal volume to the first one.
6. Send both samples for analysis.

The difference in nutrients between both solution will show us what we should initially be doing to maintain a consistent composition of the nutrient solution, given the interaction with the media. If the interaction is too strong it can also tell us that we shouldn't be using this media without previously treating it to ensure the imbalances do not happen. For example media like biochar can have an extremely high affinity for metal chelates and nitrogen compounds, if we ran our solution through the media and it turns out that it soaked

up almost all of our iron and ammonium, we wouldn’t want to just add more nitrate and heavy metals but we would like to pretreat the media with a concentrated solution and then repeat the test to ensure that the media is at a level of activity that we can correct for.

A given media source that is acceptable should not strongly affect the nutrient solution. Any media that does this in the media exchange test requires correction so that the ability to take elements from the nutrient solution is reduced. The test will tell you exactly what the media is finding most appetizing and the treatment options will then be substantially easier to plan. A coco coir that shows it soaks up almost all the Ca will need to be treated with a Ca nitrate solution and a biochar that absorbs a lot of ammonium will need to be treated with an ammonium sulfate solution. These are some cheap pretreatments that will save a lot of heartache within a hydroponic setup and will make the ongoing growing process substantially easier to manage.

This is one of the simplest and cheapest tests that can be done to address media effects. However it is by no means comprehensive in that it does not show us other important media properties that might be crucial for selection. It is important to consider that this test gives us only a glimpse of the chemical properties and the interactions with the actual nutrient solution we intend to use. Other media specific analysis and more complicated media run-off tests can be necessary to address the full extent of the interactions through an entire crop cycle.