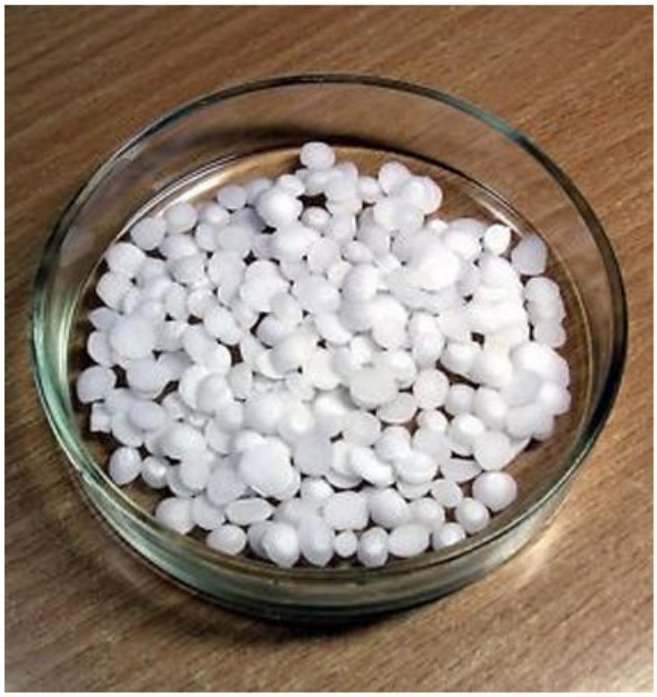
A guide to different pH up options in hydroponics

When is pH up needed?

The control of pH in hydroponics is critical. Most commonly, we need to decrease the pH of our solutions as most nutrients will initially be at a higher than desired pH. This is especially true when tap water or silicates are used, as both of these inputs will increase the overall pH of hydroponic nutrients after they are prepared. In recirculating systems, pH will also tend to drift up due to the charge imbalance created by the high active uptake of nitrate ions carried out by most plant species. For a discussion on pH down options, please read my previous post on this topic.

However, there are certain circumstances where the pH of hydroponic solutions needs to be increased. This can happen when tap water or silicates are not used or when plants decrease pH due to an aggressive uptake of some cations. Plants like tomatoes can do this when grown in solutions with high potassium contributions, as they will actively uptake these nutrients to the point of changing pH balance. Excess ammonium can be another common cause for pH decreases in hydroponic solutions that require the use of pH up solutions.



Potassium hydroxide pellets, the most powerful pH up option available to growers

With this in mind, let’s discuss the pH up options that are available in hydroponics. I only considered substances that are soluble enough to create concentrated solutions, such that they can be used with injector systems.

pH up options

Sodium or potassium hydroxide (NaOH, KOH)

These are the strongest. They are low cost, can be used to prepare highly concentrated solutions and will increase the pH most effectively. They are however unstable as a function of time because they react with carbon dioxide from the air to form sodium or potassium carbonates. This means that their concentrated solutions need to be kept in airtight containers and that their basic power will decrease with time if this is not the case. Additionally, these hydroxides are extremely corrosive and their powder is an important health hazard. Dissolving them in water also generates very large amounts of heat – sometimes even boiling the water – which makes their

usage more dangerous. Although desirable when basic power is the most important short term concern, I recommend to avoid them giving their PPE requirements and the lack of long term stability.

When these hydroxides are used, potassium hydroxide is the recommended form, as potassium hydroxide is both more basic and a plant nutrient, while excess sodium can cause problems with plant development. However, sodium hydroxide might be more desirable if it can be obtained at a particularly low price and small additions of sodium are not a concern.

Potassium silicate

This is a soluble form of silicon that is stable at high pH values. While solutions of potassium silicate by itself can be prepared and used as a pH up option, it is usually stabilized with a small addition of potassium hydroxide to take the pH of solutions to the 11-12 range. Potassium silicate contributes both potassium and silicon to hydroponic solutions – both important nutrients – and its use can be more beneficial than the use of pure potassium hydroxide. While silicates are less basic and more mass is required for the same pH buffering effect, the preparation and handling can often be much simpler than those of potassium hydroxide.

Note that potassium silicate solutions are also unstable when left in open air, as they will also react with atmospheric carbon dioxide to generate potassium carbonate. It is also worth noting that not all potassium silicates are the same, when looking for a highly soluble potassium silicate for hydroponics, make sure you get potassium silicates that have higher K/Si ratios. Usually ratios of at least 1.05 are required (make sure you convert both K and Si to their elemental forms, as most of these products report K as K_2O and Si as SiO_2).

Potassium carbonate (K_2CO_3)

This basic salt is stable in air, has less demanding PPE requirements and can also be used to prepare concentrated solutions (more than 1g of potassium carbonate can be dissolved per mL of water). Because of its lower basicity compared to potassium hydroxide, more of it also needs to be used to increase the pH of a hydroponic solution. However, solutions of it are stable, so there is no concern for their stability or changes to its basic power.

Another advantage given by potassium carbonate is that – contrary to the previous two examples – it does increase the buffering capacity of the solution against pH increases, due to the addition of carbonate to the solution. As carbon dioxide is lost to the air at the pH used in hydroponics, the pH of the solutions tends to drift up, this means that the carbonate addition makes the pH more stable in solutions where the pH is being constantly pushed down. This is all part of the carbonic acid/bicarbonate equilibrium, which also helps chemically buffer the solutions at the pH used in hydroponics.

Overall potassium carbonate is one of my favorite choices when there is a downward drift of pH in recirculating solutions.

Potassium phosphate (K_3PO_4)

Another weak base, potassium phosphate, can be used to prepare concentrated solutions and increase the pH in hydroponic solutions. While its solubility and basicity are lower than that of potassium carbonate, it does provide additional phosphorus that can buffer the pH of the solution. This happens because mono and dibasic phosphate ions are anions that be taken up by plants, therefore decreasing the pH. While phosphates can help chemically buffer the hydroponic solution against pH increases, for decreases the phosphate buffer is ineffective as the pKa of the relevant equilibrium is 7.2.

An issue with potassium phosphate is that it provides large contributions of K to solution. These potassium additions can be quite counter productive if the cause of the pH drift towards the downside is related to potassium uptake.

Potassium Citrate/Lactate/Acetate

Basic organic salts of potassium can also be used to increase the pH. These are all much weaker than even the carbonate and phosphate bases mentioned above and relatively large additions are required for even a moderate immediate effect in pH. However, since these anions are actively taken up by microbes, the microbial metabolism of these ions will create a longer term effect on pH. A moderate addition of potassium citrate can only cause a small increase of pH in the short term, with a larger increase happening during the following 24 hours.

A disadvantage is that these anions can also lead to explosions in bad microbe populations if the environment does not have an adequate microbial population. When these salts are used, adequate microbial inoculations need to be carried out to ensure that the microbes that will proliferate will not be pathogenic in nature.

Protein Hydrolysates

While hydrolysates themselves can have an acidic pH when put in solution, their microbial metabolism aggressively increases the pH of solutions in the medium term. This means that these hydrolysates should not be used for immediate pH adjusting, as they will tend to decrease pH further in the very short term, but they can be used as a more long term management option.

As with the above organic salts, their use also requires the presence of adequate microbial life. If you neglect to properly inoculate the media before their addition, then pathogens can also make use of these amino acids to proliferate.

Combinations are also possible

As with the case of pH down options, some of the best solutions for a problem come when several of the above solutions are combined. For example the use of potassium rich pH up solutions in microbe containing soilless media can often cause pH drift issues related with potassium to worsen. For this reason, it can be desirable in these cases to prepare pH up solutions that include protein. This means that you reduce the pH fast but then you have a residual effect from protein metabolism that helps you fight the pH increase as a function of time.

However not all pH up drifts are caused by potassium, as in the case of plants where pH up drift happens due to low nitrate uptake (for example some flowering plants that stop producing a lot of additional leaves during their flowering stage). In these cases potassium based pH up solutions cause no additional issues and combinations of potassium carbonate and potassium phosphate might be best.

Choose according to your goals

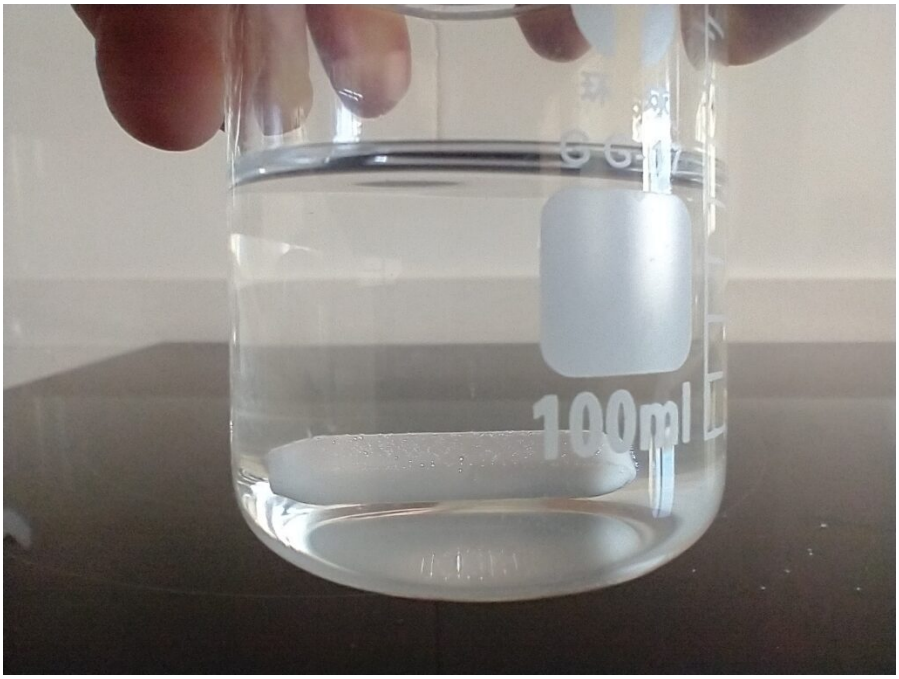
As in most cases, the best solution will depend on your circumstances. Think about whether you're just adjusting the pH of your initial solutions or whether you need to compensate for a constant drift, whether microbial life is present and whether you're concerned with the accumulation of any substances in a recirculating solution. Once you consider these factors and review the above solutions, you should be able to find the pH up solution that is better suited to your particular needs.

Are you using a pH up? Let us know why and which one you're using in the comments below!

How to make a stabilized ortho-silicic acid solution with only 3 inputs

In a previous post, which you can read here, I gave a procedure for the preparation of a stabilized mono-silicic acid using from potassium silicate. The procedure called for the usage of several stabilizing agents, including carnitine and propylene glycol, with phosphoric acid being used as the acidifying agent.

After trying this synthesis myself and talking with other people who tried this process, it seemed clear that the success rate was low and that the process was just too complicated and imprecise for most people to carry out (especially for the patience needed for the addition of the solid potassium silicate). There is a detailed discussion about this procedure, as well as mono-silicic acid synthesis in this forum thread.



Stabilized mono-silicic acid solution created using the procedure below. Note that mono-silicic acid and ortho-silicic acid are the exact same thing, they are two names for the same molecule (H_4SiO_4). Another molecule with the same nomenclature is ortho-phosphoric acid (H_3PO_4), which is also called mono-phosphoric acid.

Given these issues, I decided to look for a potentially easier synthesis starting from cheaper, more readily available materials, avoiding the use of Propylene Glycol (which concerned some people) and trying to simplify the steps involved.

The procedure I came up with simplifies the process by relying on the interaction of silicic acid with sorbitol as a stabilizing agent. This stabilization process is well documented in the literature (see here) and is caused by the formation of highly stable polyolate complexes between mono-silicic acid and molecules like sorbitol. These complexes form because molecules like sorbitol have adjacent hydroxy groups in what we call a *threo* configuration. These do not exist in sugars like glucose or sucrose, reason why these do not work for this process.

The raw inputs you will need are as followed

1. A potassium silicate with a high K/Si ratio, such as AgSil 16H. You can also use a liquid potassium silicate, such as Grotek Pro-silicate.
2. Sulfuric Acid (>90%)
3. Sorbitol
4. Distilled water.

If using AgSil16H follow this process first. In a 1000mL beaker, add 70g of AgSil16H and 450mL of distilled water. Stir – ideally with magnetic stirring – until the silicate has all dissolved. This will be the silicate solution.

This is now the procedure to prepare the stabilized ortho-silicic acid solution (700mL):

1. In a 1000mL beaker, add 500mL of distilled water and a magnetic stirrer.
2. Weigh 200g of Sorbitol and add them to the water.
3. Start the magnetic stirring.
4. After the sorbitol has completely dissolved, during a period of 30 seconds add 100mL of the silicate solution (either as prepared above or a commercial silicate equivalent to the Grotek suggestions above (around 7.5% Si as SiO_2)).
5. Stir the silicate and sorbitol solution for 10 minutes.
6. Add 10mL of >90% sulfuric acid and stir for 5 minutes. The pH should now be lower than 2.
7. The solution can now be stored.

The above process creates a stable mono-silicic acid solution that has an Si concentration of around 1% of Si as SiO_2 and around 0.6% K as K_2O. **Used at 8mL gal it should provide around 20ppm of Si As SiO_2 and 10 ppm of K.**

A previous version of this procedure used 50mL of 80-85% phosphoric acid. However, phosphoric acid seems to generate solutions that are unstable after 1-2 weeks of preparation. Solutions prepared per the above process have been confirmed

to be stable for at least 1 month.

Did you try it? How were your results? Let us know in the comments below!

A one-part hydroponic nutrient formulation for very hard water

What is water hardness?

There are many parameters that determine the quality of a water source. Water that has a composition closer to distilled water is considered of a higher quality, while water with many dissolved solids or high turbidity is considered low quality. Calcium carbonate, magnesium carbonate, calcium sulfate and calcium silicate are some of the most common minerals that get dissolved into water as it runs through river beds and underground aquifers. The carbonates and silicates will make water more basic, will increase the water's buffering capacity and will also increase the amount of magnesium and calcium present in the water.

Water hardness is determined experimentally by measuring the amount of Calcium and Magnesium in solution using a colorimetric titration with EDTA. Although both Calcium hardness (specific amount of Ca) and Magnesium hardness (specific amount of Mg) are measured, total water hardness (the sum of both) is the usually reported value. The result is often expressed as mg/L of $CaCO_3$, telling us how much $CaCO_3$ we

would require to get a solution that gave the same result in the EDTA titration.

The Calcium and Magnesium present in water sources with high hardness is fully available to plants – once the pH is reduced to the pH used in hydroponics – and it is therefore critical to take these into account when formulating nutrients using these water sources. *It is a common myth that these Ca and Mg are unavailable, this is not true.*

What about alkalinity?

Water alkalinity tells us the equivalent amount of calcium carbonate we would need to add to distilled water, to get water that has the same pH and buffering capacity. An alkalinity value of 100 mg/L of $CaCO_3$ does not mean that the water has this amount of carbonate, but it means that the water behaves with some of the chemical properties of a solution containing 100mg/L of $CaCO_3$. In this particular case, it means that the water requires the same amount of acid to be titrated as a solution that has 100mg/L of $CaCO_3$.

Water sources with high hardness will also tend to have high alkalinity as the main salts that dissolve in the water are magnesium and calcium carbonates. Since these carbonates need to be neutralized to create a hydroponic solution suitable to plants, the anion contribution of the acid that we will use to perform the neutralization needs to be accounted for by the nutrient formulation.

An example using Valencia, Spain

Valencia, in the Mediterranean Spanish coast (my current home), has particularly bad water. Its water has both high alkalinity and high hardness, complicating its use in hydroponics. You can see some of the characteristics of the water below (taken from this analysis):

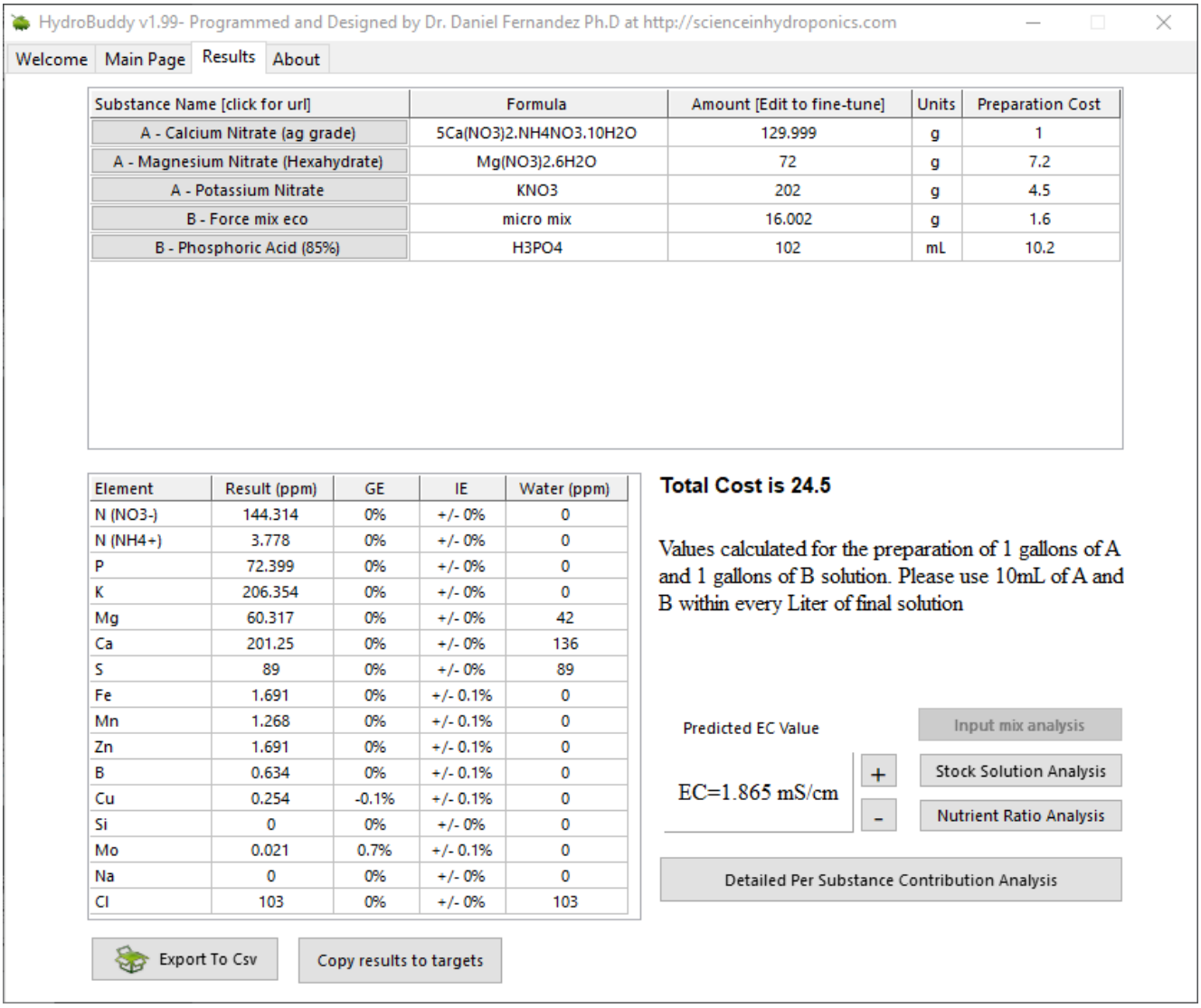
Name	Value	Unit
Calcium	136	ppm
Magnesium	42	ppm
Chloride	103	ppm
Sulfur	89	ppm
pH	7.6	
Alkalinity	240	mg/L of $CaCO_3$

Typical water quality values for water in Valencia, Spain.

Hard water creates several problems. Since Calcium nitrate is one of the most common sources of Nitrogen used in hydroponics, how can we avoid using Ca nitrate? Since we have more than enough. Also, how can we neutralize the input water so that we can make effective use of all the nutrients in it without overly increasing any nutrient, like P, N or S, by using too much of some mineral acids?

Creating a one-part solution for very hard water

HydroBuddy allows us to input the characteristics of the input water into the program so that we can work around them while designing nutrient solutions. To get around the above mentioned problems – but still ensure I could easily buy all the required chemicals – I decided to use a list of commonly available fertilizers. I used Calcium Nitrate, Magnesium Nitrate, Potassium Nitrate, Phosphoric acid (85%) and a micro nutrient mix called Force Mix Eco (to simplify the mixing process). This micronutrient mix is only available to people in the EU.



HydroBuddy results to create 1 gallon of 1:100 nutrient solution for Valencia's very hard water.

Note that we use absolutely no phosphates or sulfates, since the solution already contains more than enough sulfur (89 ppm) and we need to add all the Phosphorus as phosphoric acid to be able to lower the alkalinity. I determined the amount of P to add by setting P to zero, then using the "Adjust Alkalinity" to remove half of the alkalinity of the water using phosphoric acid. This is more than enough P to be sufficient for higher plants. The above nutrient ratios should be adequate for the growth of a large variety of plants, although they are a compromise and not ideal for any particular type of plant.

Since we are adding no sulfates and the pH of the solution is going to be very low (because of the phosphoric acid), we can add all of these chemicals to the same solution (no need to

make A and B solutions). The values in the image above are for the preparation of 1 gallon of concentrated solution. This solution is then added to the water at 38mL/gal of tap water to create the final hydroponic solution.

Does it work?

I have experimentally prepared the above concentrated solution – which yields a completely transparent solution – and have created hydroponic solutions I am now using to feed my home garden plants. After adding to my tap water – initial pH of 7.6 – I end up with a solution at a pH of 5.6-5.8 with around 1.5-1.8mS/cm of electrical conductivity. The plants I'm currently growing – basil, rosemary, chives, mint, malabar spinach and spear mint – all seem to thrive with the above solution. I am yet to try it on any fruiting crops, that might be something to try next year!

Are you growing using hard water, have you prepared a similar one-part for your hard-water needs? Let us know what you think in the comments below!

New tissue analysis feature in HydroBuddy v1.99

Tissue Analysis

To grow great plants, we need to grow plants that have a healthy mineral composition. Although there are no theoretically established values for what the mineral composition of a plant should look like, we have grown healthy

plants and have established, through analysis of their tissue, what this mineral composition should empirically be. By sampling the leaf tissue from your plants and sending it to a lab for analysis, you can know what the composition of your tissue is and how it compares to healthy plants grown by others.

The question is, can we create a nutrient formulation just from the tissue composition we want to get?

Nutrient solution targets from tissue analysis

Turns out, you can figure out the elemental concentrations that are required in solution to get to certain concentrations in tissue. My colleague and friend – Bruce Bugbee – proposed in this paper about nutrient management in 2004 how this could be done. To achieve this, we make the assumption that all elements taken up by the plant will be deposited as minerals upon transpiration – because minerals cannot leave the plant as gases – so knowing the amount of water that will transpired per amount of tissue grown, we can figure out how much of that element needs to be in the water.

The volume of water required to grow a certain mass of tissue is called Water Use Efficiency (WUE). It is expressed as gram of tissue per liter of water transpired and has values from 3.0 to 6.0. Higher WUE values imply the plant is growing more efficiently, requires less water to grow the same mass of tissue, while a lower WUE implies the plant is less efficient and needs to transpire more to grow. Conditions that increase growing efficiency and decrease transpiration, such as carbon dioxide enrichment and high humidity, tend to increase WUE, while conditions that create inefficient growing – like low humidity with high temperature – tend to decrease it.

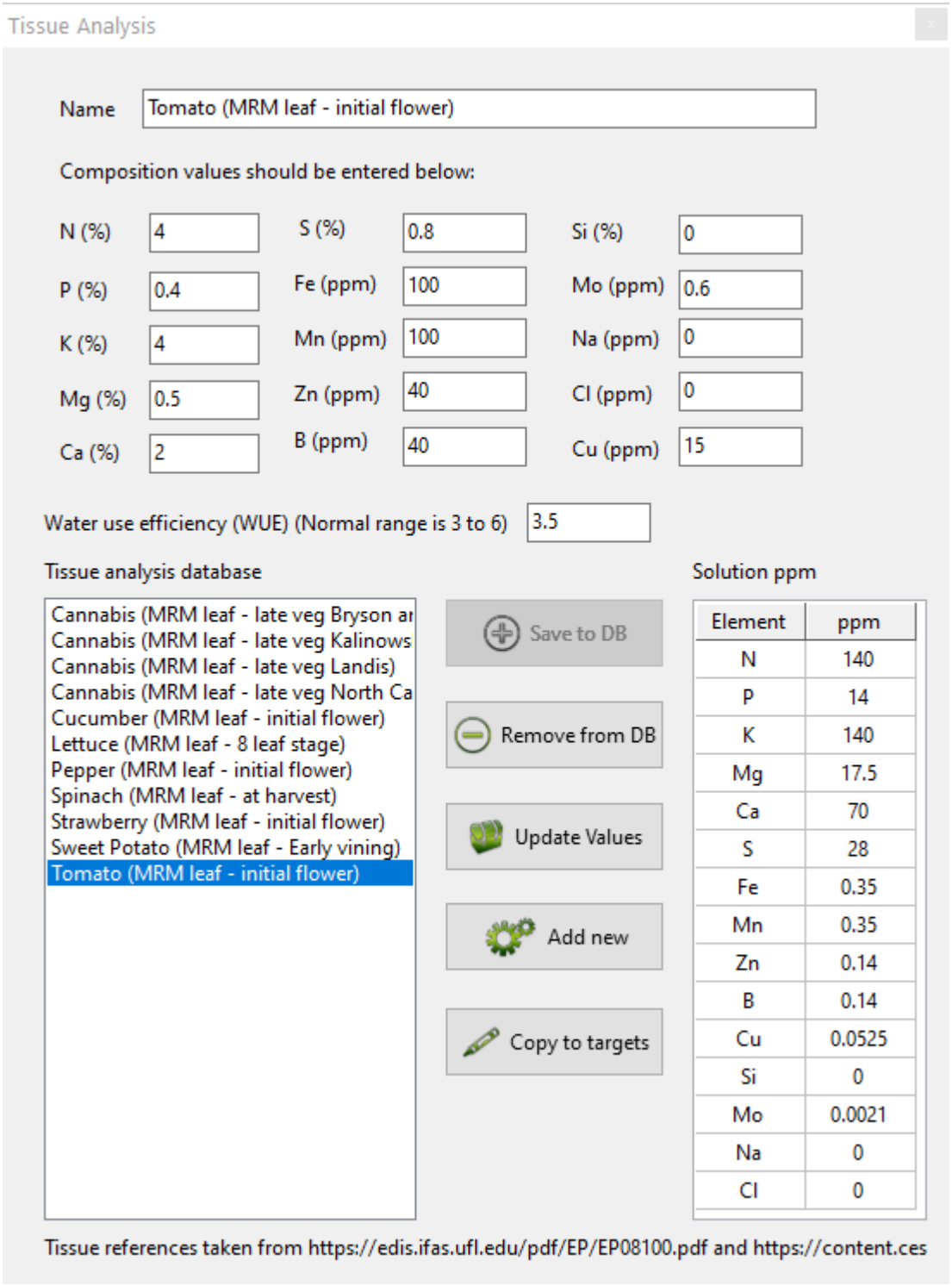
If we grow plants with a solution where we determine the

nutrients according to the WUE and the concentrations in tissue we want, we can create very effective solutions that lower the probability of over accumulation of nutrients in the root zone and the solution. This allows for solutions that require no dumping and create very healthy plants in recirculating systems (for which Deep Water Culture, DWC, is the most common example).

Doing this process in HydroBuddy

From v1.99, HydroBuddy now includes a “Tissue Analysis” dialogue that allows you to use target tissue concentrations and a certain WUE value, to figure out what the required nutrient concentrations in a hydroponic solution would be like. The program also includes a small Database with tissue targets for certain plants and certain stages of development. There are also a couple of links that point you to resources where you can find a wide variety of different plant species and development stages if the ones that interest you are not included in the software’s default DB configuration.

The image below shows you an example where I determined the target solution concentrations required to grow a tomato plant that has the composition expected for a tomato plant in early flower.



Nutrient solution targets for a hydroponic solution to grow tomatoes with a leaf tissue composition equal to that expected for tomatoes under initial flower (MRM = most recent mature leaf). This assumes the WUE is 3.5 g/L.

How do I figure out the WUE?

As you can see, the above process requires you to input the WUE. This ranges from 3 to 6. It is not easy to measure in the

environment, so the best practical solution is to assume your WUE is about 3.5 (the default value), prepare solutions with those concentrations and then observe how the EC of the solution changes as a function of time.

A solution that is prepared with a concentration that would be appropriate for the exact WUE of the plants will have an initial decrease in EC – as nutrients that are taken actively are rapidly taken up – followed by more stable to slightly decreasing EC conditions as uptake changes to be mostly passive. This cycle is repeated when solution is replenished to recover the initial volume in a recirculating system. A solution that is prepared too concentrated will have an increasing EC while a solution that is prepared too diluted will show a consistently decreasing EC. If your EC decreases more sharply with time then you need to assume a higher WUE, if your EC increases then you need to lower your WUE assumption.

Limits of the approach

While this approach can be very useful to create long lasting solutions, especially in recirculating systems, it suffers from some important limitations.

The first is that it doesn’t account for changes in uptake due to changes in pH or availability in solution. This is the reason why the recommendations for elements like Fe and Mn, might be significantly lower than what you commonly see in nutrient solutions. In the above example, the solution requires only around 0.35ppm of Fe, but this means we need 0.35ppm of fully available Fe for the plant, which in reality might mean having 1.5ppm of Fe or more of added Fe, depending on the chemical form of Fe and the pH of the solution.

The above implies that values should not be used without considering the context and that this context might be much more important for some nutrients, for example micro

nutrients, than for other elements, for example K and Ca, for which the availability windows and plant uptake are much more straightforward. The plant characteristics should also be taken into account. While a leaf tissue derived approach might only require 50 ppm of Ca in a lettuce crop, we know we need to feed more due to the poor water transport of this plant into new leaves.

Second, the approach assumes that all we care about is leaf composition. This is a perfectly fine if we are growing leafy greens, but if you're growing a tomato plant, the composition will be heavily split between leaves and fruits as soon as flower pollination ends. For this reason, the nutritional needs of other important tissues – such as sink organs – should be considered very carefully when following this approach. In the case of tomatoes, this might mean feeding substantially higher levels of K, as this element has a much higher concentration in fruits than it has in leaves.

Crops that have changing nutritional needs due to changes in the composition of the tissue formed, require different nutrient solutions as a function of time, as we need to match the overall expected composition of the entire plant, not just the leaves.

Conclusions

Nutrient formulations do not need to be just trial and error. Up until now, besides a formulation database, HydroBuddy had no feature to help growers create formulations with any scientific basis. This new feature, introduces the ability to use target leaf tissue composition and WUE as a way to guide the initial formulation of nutrient solutions. While you still need experience to figure out when to overrule these values and increase or decrease concentrations, it does provide basic blue prints to build from. An analysis of how a formulation derived from tissue compares with your current formulation

might also give you some insights into whether you are over or under feeding any elements.

Have you use the HydroBuddy's leaf tissue analysis feature? Leave us some comments below!

The importance of accuracy in hydroponic nutrient preparation

When you prepare your own concentrated hydroponic nutrients, you need to carry out a significant number of measurements. As a consequence, you will deviate from your intended preparation by the errors inherent to these operations. Plants tolerate a significant array of conditions, so these errors – even though sometimes quite big – are often not big enough to kill plants and are therefore ignored by growers. These errors will, however, greatly hinder your ability to optimize and evolve your crop nutrition to a higher standard. In this post, we will talk about these errors, why and how they happen, when they are important, and how you can minimize them in order to obtain more reproducible results.

The markings in buckets can carry high systematic and random errors.

Types of error

Systematic Error

There are two types of errors that happen when anything is measured. The first is systematic error, which is the error inherent to calibration problems of the instrument. For example, you might be using a 1 gallon jug to prepare concentrated nutrients and always filling the jug to a mark you made on it. This mark is not going to be 1 gallon, but probably significantly over or under it. As long as you always use the same jug and fill to the same mark, this large deviation from 1 gallon will always be the same. As long as the measuring instrument is unchanged – meaning not recalibrated – the systematic error always remains the same in sign and magnitude.

Random Error

The second type of error relates to the randomness of the measuring process. Imagine that you used a sharpie to make the mark on the above-mentioned one-gallon jug, and you always try to measure to the same mark. The mark has some width, sometimes you will fill your jug up to the bottom of the mark, sometimes up to the top. Sometimes the surface where you place the jug where you measure will not be perfectly leveled, so the mark will be off because it will be higher at one side of the jug vs the other, etc. This error changes randomly, every time you measure. One time you might be +1%, the other -4%, etc.

Where the biggest errors happen

When you make your own hydroponic nutrients, you will be measuring two things: volume and mass. These two measurements will both carry systematic and random errors. The errors in scales are more obvious, so growers will always make an effort to get scales that are accurate enough for the measurements they want to make. For small growers, this means getting

scales that can measure +/-0.01g with a decent capacity, normally 500g is fine. Buying weights to properly calibrate these scales is also recommended, in order to reduce systematic errors as much as possible.

However, always make sure you read at least 3 significant digits when making a weight measurement. This means if you need to measure 1.673485g, you need a scale that measures at least 2 digits, so that you can measure 1.67 +/- 0.01g. This will keep your error below the 1% mark. This is why it is often common to also get a +/-0.001g scale, to measure things like sodium molybdate. You can also go around this problem by preparing more concentrated solution, as your weights become larger, with larger volumes.

Volumes however are where the largest errors are accrued. Most growers will use non-calibrated receptacles to measure volume. The fact that something has a line drawn on it with a volume marking, does not mean that this line is accurate. The systematic errors in these receptacles are usually very large because these were never intended for accurate measurements of volume. **Things like buckets, beakers, tanks, and jugs, should not be used to measure volumes**. Wide containers, like buckets and tanks, also enhance errors that relate to parallax – your ability to judge whether a level of water is at a line – so the random component of your error will be quite large.

Consequences in nutrient values

In the best cases – for jugs, buckets, and tanks – the systematic error is around 10% with a random error of +/- 5% (3 sigma). If you are preparing a concentrated solution where the final expected concentration after dilution is 200 ppm of K, then this means that your actual K value in solution will start by being 10% over or under it – depending on which way the systematic error of your volume measurement goes – and then deviate +/-5% from there. This means that you are

expected to get values all the way from 170 to 230 ppm in the final solution.

This is fine as far as keeping plants alive goes. A solution with 170 ppm will keep plants alive as well as a 230ppm solution would. This is the reason why most growers don’t see an immediate need to reduce these errors. If you’re growing healthy plants and you have less or more than what you intended, what is the problem?

How inaccuracy affects your process

There are three ways in which having inaccurately prepared solutions can affect your process. The first is that it makes you very vulnerable to changes. The second is that it makes it difficult for you to effectively optimize your setup, and the third is that it prevents others from being able to reproduce your results.

Changes in your setup can affect you deeply

Let’s say you optimized your nutrients with time and found that the optimal is 200ppm of K. In reality you have a bucket that always measures 10% less volume and you randomly deviate +/- 5% from that as well. This means that your final solutions are majorly in the 210-230 ppm range. Your trusty plastic bucket then cracks and you need to go and buy another one, you suddenly find that you’re not getting the same results. Now you have a bucket that just by chance, happens to measure the volume more accurately. You are now feeding 190-210ppm, substantially less K. You never knew that, you’re confused, you’re preparing everything the same way.

Your ability to optimize is hindered

The second problem is similar. Let’s say you prepared a batch

of concentrated solution to compare feeding K at 180 ppm and K at 200 ppm. You prepare a single-stock solution to carry out the test. This bucket has a systematic error of +10% and a random error of +/-5%. For this batch, the solution happens to be 6% more concentrated than intended (+10% systematic, -4% random), so you end up with 190.8ppm and 212ppm. You find out that the 200 ppm preparation works better, so you decide to use it.

However, you run out of the stock solution you prepared for the experiment, so you prepare it again. However, you incur a different random error in this preparation – remember random errors are different every time you measure – and you end up being with a +1% random error, so a +11% total error. Your results are not as good as before, you don't know why. The reason, you're feeding 222ppm while in your previous experiment you had fed 212ppm. All while thinking you were feeding 200 ppm.

It becomes hard to share

Systematic and random errors can make effective sharing of results impractical. Imagine you have optimized your setup to the point where you're sure that the solution you prepare is the best one for a given plant under some given conditions. Then, you want to share this with another grower and tell him how to mix your formulation. This person tries it and tells you that your solution doesn't actually work the way you think. You might both be aiming for the same targets but hitting completely different numbers in reality. When sharing, it is important to share the numbers you aim for, as well as the error related to these values.

How to reduce errors

Prepare highly accurate small scale solutions

The easiest way to reduce errors when preparing hydroponic solutions is to base all preparations on small-scale experiments where the preparation can be done much more accurately, using calibrated volumetric material. Watch my videos on preparing hydroponic solutions, how to correctly prepare dilutions and how to characterize stock solutions, to learn more about how this is done.

Volumetric flasks can be used for highly accurate small scale preparations

The idea is that these small-scale preparations can tell you things such as: the amount of water you need to add for a given volume of stock solution, the expected conductivity of dilutions, and the expected density of the stock solution. Remember that salts take up volume, so to prepare 1 gallon of

a concentrated stock solution you will need much less than 1 gallon of water. With this information, you can then prepare larger amounts of stock solutions, since you know the exact amount of water to add for a final volume, which you can accurately measure with a flow meter instead of having to use markings of any kind. You can then use the density measurement to check the accuracy of the preparation.

Perform fewer measurements

Every measurement you make incurs an additional error. It is better to prepare 2 concentrated nutrient solutions than to have 10 solutions with the salts being separated because you need to make 8 fewer volume measurements. If you minimize the number of measurements that you need to do to arrive at the nutrient solution that is fed to plants, you will also minimize the error incurred in these measurements. Minimize measurements from instruments with high errors. If your volumes have much more inaccuracy than your weights, prioritize lowering the number of times you measure volume vs weights.

Conclusion

Accuracy is something to strive for. It closes no doors, only opens them. It is not about being overly fuzzy or obsessive about it, it’s about using it to help you get better. Better practices, lower errors, more reproducibility, more learning. It’s a virtuous cycle. Errors are always there, whether you’re aware of them or not. Ignore them at your own peril.

If you have a process that is inaccurate that generates significant variations in your nutrient solution makeup, then these will be a problem, one way or another. You might be unable to judge whether changes in your crop are due to errors or due to changes, you might be unable to reproduce results and you might find yourself unable to meaningfully share

results and explore with others. High accuracy is often not substantially expensive in hydroponics – instruments for accurate small-scale preparation are generally below the 200 USD mark total – and they can dramatically enhance the quality of your solutions and the conclusions you can make from experiments.

Do you prepare your own nutrient solutions? Do you know what your systematic and random errors are? Share with us in the comments below!

How to make an organic hydroponic nutrient solution

Hydroponic nutrients are usually made with synthetic chemicals that come from industrial processes. While these chemicals are usually of a higher purity than those mined or obtained from animal or vegetable resources, it also means that these products contain no microbes or bio-stimulants and their origin implies they cannot be used in organically certified growing operations. Growers who want a more organic approach might still want to use hydroponic solutions, but traditional hydroponic fertilizers cannot be used due to the fact that they lack many of the traits desired in an organic fertilizer. In this post, I will show you how you can create a complete hydroponic solution from scratch using only OMRI-approved raw materials.

This seal is given to products that have been approved by the OMRI organization, which certifies which products can be used in organic culture

OMRI nutrient sources

A complete hydroponic solution should provide all substances that are necessary for plant growth. This means we need to provide nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, zinc, boron, copper, molybdenum, and manganese. Furthermore, we need to ensure that all of these nutrients are provided in forms that are available for the plants. This means we need to find sources that contain all the elements we need and then create a process that makes all of these nutrients adequately bioavailable. The following are the nutrient sources that we will be using, all of them are OMRI listed:

Please note the amazon links below are referral links. This means that I get a small commission when you choose to buy the products through these links, at no extra cost to you.

- Bark compost
- Solubor
- Copper Sulfate
- Corn Steep Liquor
- Ferti-Nitro Plus

- Iron Sulfate
- Magnesium Sulfate
- Manganese Sulfate
- Potassium Sulfate
- Seabird Guano
- Zinc Sulfate

Mixing the solution

This solution cannot be created in a concentrated form. This means we will be preparing a solution that will be fed directly to plants. However, since many of the inputs contain a lot of insoluble materials – due to their origin – there will need to be a filtration process in the end. This filtration step is necessary if you want to avoid problems dealing with the clogging of irrigation lines, in case you want to feed this into a regular irrigation system. If you want to hand water directly, then you can avoid this filtration step.

Since the solution is not concentrated, the amounts to be weighed can be small for some of the materials. For this reason, I advise you to prepare at least 100 gallons of solution, so that you don't require to weigh very small amounts of material. This will help keep the errors due to measurements low. To make this preparation you will need the following materials:

- A tank that can hold 100 gallons
- A flow meter to measure water flow
- A scale that can weight +/-0.01g max 500g
- An air pump rated for at least 100 gallons of water
- Air stones to diffuse air

To prepare the solution (100 gallons), follow these steps:

1. Add 50 gallons of water using the flow meter. Ideally use RO water, but you can use tap water as well if that

is not possible.
2. Weigh and add all the ingredients per the table below.
3. Add another 50 gallons of water using the flow meter.
4. Place the air pump inside the solution and switch it on.
5. Maintain constant aeration for at least 15 days. Do not use it before this time has passed.
6. After 15 days have passed, filter the solution to use in irrigation lines or use directly to hand water. Keep air flowing through the solution even after the 15 days have passed.
7. The solution might also become basic during this process, if necessary, you can bring the pH of the solution down with citric acid before watering plants.

Bark compost	190
Solubor	0.65
Copper sulfate	0.15
Corn Steep Liquor	330
Ferti-Nitro Plus	220
Iron Sulfate	4
Magnesium sulfate	190
Manganese Sulfate	1
Potassium Sulfate	136
Seabird Guano	265
Zinc Sulfate	0.10

Table of ingredients to weigh. Masses are in grams.

The reason for the long wait

Plants ideally require nitrate in order to grow, the above inputs do not contain nitrate in appreciable amounts but mainly organic nitrogen sources. In this and this previous posts, you can learn more about organic nitrogen and why it is not ideal to use this in an unprocessed manner in a hydroponic

crop. When you irrigate with organic nitrogen, most of the nitrogen will go unused and significant time will need to pass in the root zone for it to become available. The organic nitrogen decomposition process can also destabilize the pH of the root zone, making it harder for plants to properly absorb nutrients. By carrying out this process outside of the root zone, we make it easier on the plants, as we feed a pre-digested solution that is rich in available nutrients and microbes. The Seabird Guano and Bark compost, both provide the microbe inoculations necessary for the nitrogen decomposition process to take place. Oxygen, which we continuously pump into the solution, is also key to this process. The CSL and the Ferti-Nitro Plus will provide the organic nitrogen sources that will be decomposed.

This solution also contains a significant amount of amino acids. Although most of these amino acids will be converted into more readily absorbable nitrate through the digestion process, a small amount will be left undigested, which will lock onto the heavy metal ions. This will help prevent precipitation issues and provide the plant with organically derived chelates.

Also note that no specific molybdenum input is included. This is because it is present as an impurity in the corn steep liquor at a high enough concentration, so its explicit addition is not required.

Conclusion

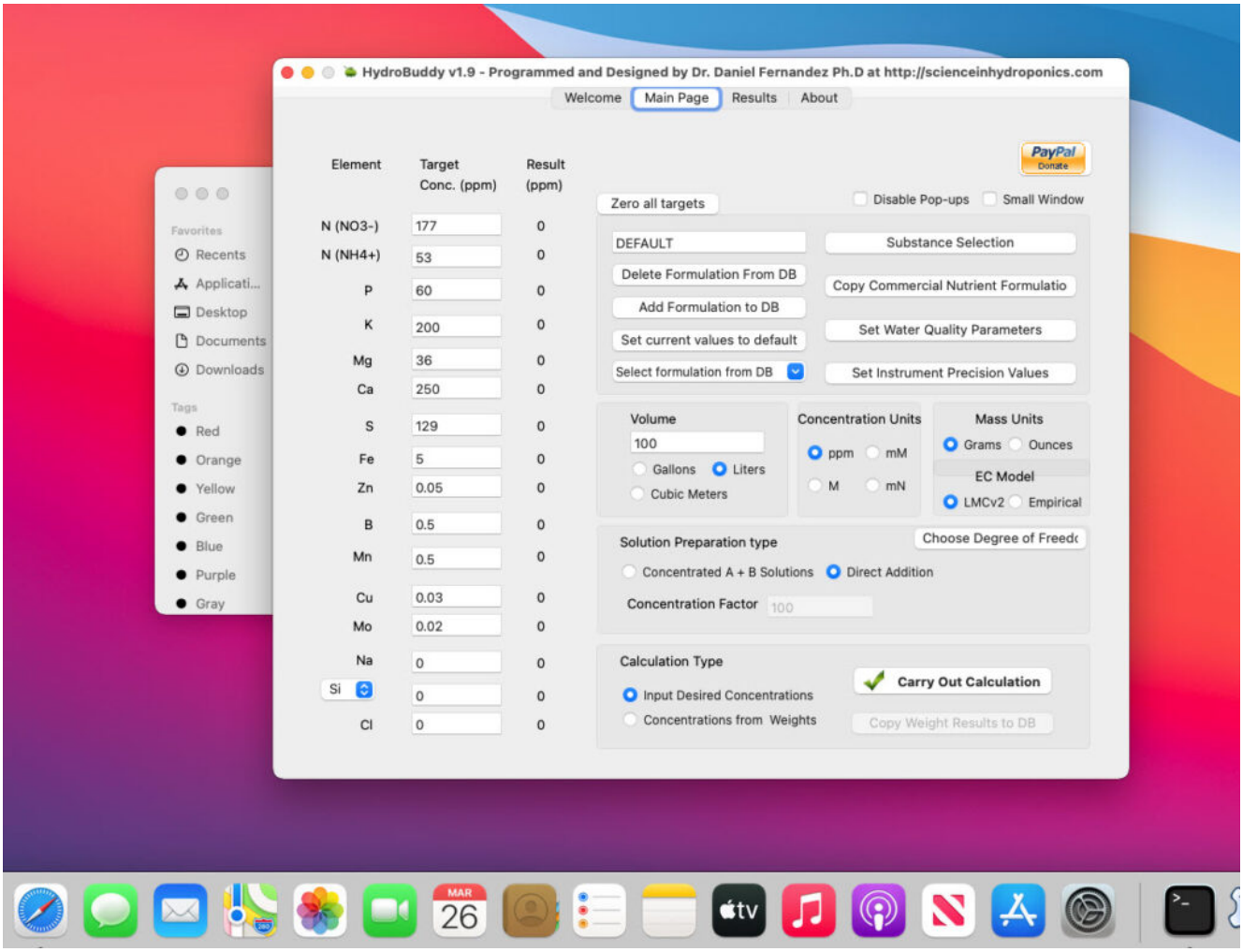
The above solution should fully replace a traditional hydroponic solution, using only OMRI-approved materials. The final concentrations of nutrients should be spot on for the healthy development of most small and large plants. The solution will also contain a lot of microbes and bio-stimulants, which will also help plant growth. Of course, the final character of the solution will depend on the temperature

of the digestion, the amount of aeration present, and the nature of the inputs used (as OMRI inputs have a significant amount of variability due to their sourcing). It might take a few tries to adjust this process to your particular conditions. Note that the above solution is intended to be used with soilless media that has not been amended, as it should provide all nutrients required for plant growth.

Did you prepare the above solution? Leave a comment telling us about your experience!

HydroBuddy v1.9, MacOS binary, new EC model, many bug fixes and more!

Today I am releasing a new version of HydroBuddy (v1.9) which contains many suggested and needed improvements from the previous version of the software. In this post I want to discuss the changes within this release and how they will affect the way things are done in the program. Some big changes have been implemented so make sure you go through the list below if you want to use this new version. **Thanks to all of you who contributed your suggestions about HydroBuddy and/or reported bugs to me.**



One of the biggest changes in this release, the return of precompiled MacOS binaries.

Here is the list of changes in this version:

- A MacOS binary compiled in Big Sur 11.0.1 has been released.
- Ability to make any formulation the “default” formulation. This selected formulation is loaded when the software is started.
- The LMC conductivity model has now been replaced with LMCv2 which is an important improvement. See here to learn more. The LMCv2 model now adjusts conductivity based on each specific ion’s charge and the overall ionic strength of the solution. It now includes no arbitrary terms.
- The treatment of liquids/solids in the program has now been changed. Instead of specifying liquid or solid (and the program having to make assumptions) users can now

select whether the percentages and substance amounts are going to be either in g and w/w% or in mL and w/v%. This should simplify the interpretation of results and the addition of substances.

- An additional column has now been added in the results page to specify the unit of the amount being calculated. When a user wants a substance's contribution to be calculated in mL, the appropriate unit will be shown here.
- When adding a new substance, all fields are reset to null values (previously the program kept the values from previously opened/updated substances).
- Density has now been eliminated as a variable used in the program since it is not needed if there is no cross between w/w% and w/v% calculations. It is only kept in the "Copy commercial nutrient formulation" dialogue.
- An error where P and K were mixed up in the product comparison window of the "Copy commercial nutrient formulation" function has now been fixed.
- The wording of options in the "Substance selection" dialogue has been changed so that the buttons better describe what they do. For example the "Delete" button has now been changed to "Do not use".
- Two buttons have been added next to the EC model prediction in order to allow users to increase or decrease the EC by adjusting all nutrient concentrations by +5%/-5%. This will allow you to see how nutrient concentration changes affect conductivity in a straightforward manner.

The above modifications are now committed to the github repository as well. Feel free to take a look if you're interested in how any of the above variations were coded into the program.

A simple cheatsheet for macro nutrient additions in hydroponics

In hydroponic growing, we are often faced with the need to adjust the nutrient concentrations of a fertilizer reservoir or foliar spray directly, in order to increase the quantity of some nutrient by a specific amount. Although you can use a program like HydroBuddy in order to quickly calculate these values, it is often the case that these calculations need to be done in the field or in a growing environment, and a computer to calculate things is not at hand. For this reason, I have created a small "cheat sheet" that you can use in order to figure out the amounts of salts that you would need to add to a solution to increase any of the macronutrients by 10 ppm.

Salt Name	**ppm**	**Element**	**ppm**	**Element**	g/L	**g/gal**
Calcium nitrate (ag grade)	10	N (NO3-)	13.19	Ca	0.0694	0.2629
MAP	10	N (NH4+)	22.1	P	0.0821	0.3108
Ammonium Sulfate	10	N (NH4+)	11.4	S	0.0472	0.1785
Gypsum	10	Ca	7.99	S	0.0430	0.1626
Calcium Chloride	10	Ca	17.69	Cl	0.0277	0.1048
Magnesium Nitrate Hexahydrate	10	N (NO3-)	8.67	Mg	0.0915	0.3463
Epsom Salt	10	Mg	13.19	S	0.1014	0.3839
Magnesium Chloride	10	Mg	29.16	Cl	0.0392	0.1483
AgSil 16H	10	Si	10.9	K	0.0411	0.1554
MKP	10	P	12.62	K	0.0439	0.1663

Potassium Nitrate	10	N (NO3-)	27.87	K	0.0730	0.2763
Potassium Sulfate	10	K	4.10	S	0.0223	0.0844
Potassium Chloride	10	K	9.067	Cl	0.0191	0.0722

Cheatsheet for macronutrient additions in hydroponics

With the above cheatsheet, you can quickly evaluate some of the most common options you would have to increase all the different macronutrients in a hydroponic or foliar solution by 10 ppm and which secondary elemental contributions you would get from these additions. For example, if you add 0.0694g/L of Calcium Nitrate, this would add 10ppm of Nitrogen as nitrate plus 13.19ppm of Calcium. Careful consideration of secondary contributions need to be taken into account, especially when using salts that contain elements that can be toxic, such as chlorides.

Standard hydroponic formulations from the scientific literature

When researchers started looking into growing plants without soil, they started to look for mixtures of nutrients that could grow plants successfully so that these formulations could be used to study other aspects of plant physiology. If you have a mixture of nutrients that you know grows a plant without major issues, then you can use that as a base to study other things, for example how plants react to some exogenous agent or how changes to temperature or humidity affect the uptake of certain nutrients (see this paper for a view into the history of hydroponics and standard solutions). The establishment of these standard solutions was one of the great

achievements of botanists during the twentieth century, which allowed thousands of detailed studies on plants to be carried out. In this post, we're going to be talking about these standard solutions and why they are a great place to start for anybody seeking to formulate their own nutrients.

ppm (mg/L)	1	2	3	4	5	6	7	8	9	10	11	12
K	132.93	187.28	241.24	312.79	236.15	237.33	89.54	157.57	261.57	302.23	430.08	312.79
Ca	136.27	36.07	149.09	163.52	200.39	160.31	161.11	120.23	184.76	172.34	220.43	160.31
Mg	19.69	18.71	37.19	49.34	48.61	24.31	55.90	48.61	49.10	50.55	36.46	34.03
N as NH4+	0.00	4.90	2.10	18.91	0.00	28.01	19.61	0.00	0.00	0.03	0.01	17.51
Na	0.00	0.23	1.15	0.46	0.00	0.46	0.00	2.07	0.46	0.69	8.74	0.69
Fe	36.86	2.79	4.02	0.00	1.44	1.12	1.12	5.03	1.34	1.90	7.10	0.84
Mn	0.00	0.62	1.23	0.00	0.50	0.11	0.14	0.40	0.62	1.98	2.40	0.55
Cu	0.00	0.06	0.01	0.00	0.02	0.03	0.00	0.02	0.01	0.10	0.04	0.04
Zn	0.00	0.01	0.01	0.00	0.05	0.13	0.13	0.05	0.11	0.10	0.12	0.03
N as NO3	123.82	77.46	161.50	226.63	210.10	196.09	112.75	112.05	167.80	201.28	241.62	224.11
P	103.45	42.74	64.74	40.89	30.97	61.95	71.24	61.95	30.66	59.78	69.69	38.72
S	25.97	27.90	54.51	65.09	64.13	32.07	96.84	64.13	111.59	67.98	87.22	44.89
Cl	0.00	0.00	0.00	0.00	0.64	1.77	0.00	0.53	0.00	0.00	13.47	0.00
B	0.00	0.28	1.19	0.00	0.46	0.27	0.10	0.40	0.43	0.30	0.34	0.27
Mo	0.00	0.41	0.00	0.00	0.01	0.05	0.00	0.03	0.05	0.19	0.06	0.34

Summary of standard nutrient formulations found in this article with the concentrations translated to ppm. The numbers in the list correspond to the following: 1. Knop, 2. Pennings-feld North Africa, 3. Pennings-Feld Carnations, 4. Gravel Culture Japan, 5. Arnon and Hoagland 1940, 6. Dennisch R. Hoagland USA, 7 Shive and Robbins 1942, 8. Hacskalyo 1961, 9. Steiner 1961, 10. Cooper 1979, 11 Research Centre Soil-less culture, 12. Naaldwijk cucumber.

One of the best places to find a comparison between these standard solutions is this paper. In it, the authors explore the relationships between the different solutions and how they are similar or diverge. In the table above, you can see a summary of the elemental nutrient concentrations found in this paper for the 12 standard solutions they compare (the paper states them in mmol/L but I have changed them to ppm as these are more commonly used units in the field nowadays). As you

can see, some of the older solutions miss some elements or contain much smaller amounts of them – as they were likely present in the media or other salts as impurities – while more recent standard solutions do contain all the elements we now understand are necessary for plant life.

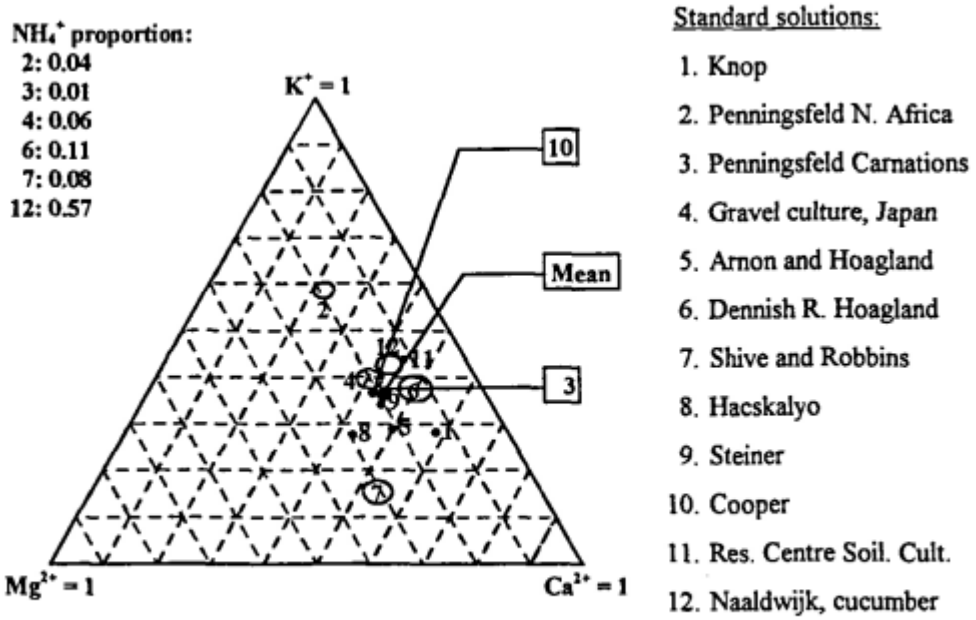


FIGURE 1. Cation composition of the standard solutions.

Figure showing the Ca/Mg/K ratio represented in a three axis plot. Taken from the paper mentioned above.

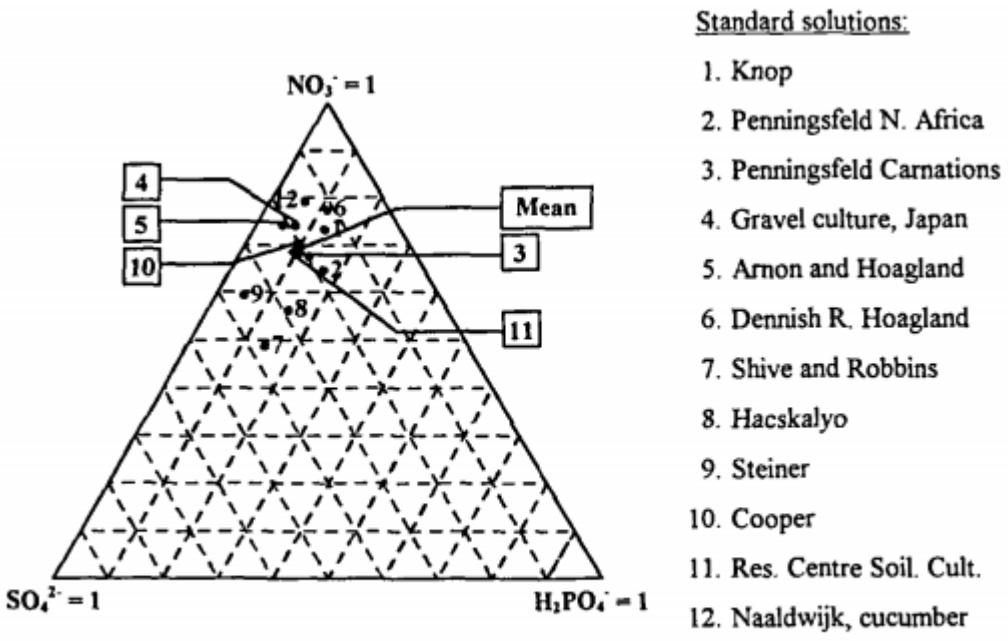


FIGURE 2. Anion composition of the standard solutions.

Figure showing the N/S/P ratio represented in a three axis plot. Taken from the paper mentioned above.

It is interesting to note that all of these solutions have been successfully used to grow plants, so their convergent aspects might show us some of the basic things that plants require for growth. As they highlight on the paper, the K/Mg/Ca ratio for most of these solutions is rather similar, as well as the N/S/P ratios. This means that most of these authors figured out that plants needed pretty specific ratios of these nutrients and these ratios are sustained with minor variations through the 12 solutions, developed across a span of more than 100 years. All the solutions developed from the 1940s have similar final concentrations and their starting pH is almost always in the 4-5 range, due to the presence of acid phosphate salts like monopotassium phosphate.

Nonetheless, there are several things that improved in the solutions as a function of time. The first is the inclusion of higher concentrations of all micronutrients with time, as macronutrient salt quality increased, the media sources became more inert and the need to add them to avoid deficiencies became apparent. The need to chelate micronutrients also became clear with time, as solutions starting with Hoagland's solution in the 1940s started using EDTA to chelate iron, to alleviate the problem of iron phosphate precipitation in hydroponic solutions. This is clearly shown in the table below, where the authors show how the first three solutions had almost or all of their Fe precipitate out, while the newest solutions, like Cooper's developed in 1979, had less than 5.5% of its Fe precipitated.

Standard solution	% Fe precipitated as $Fe_2(PO_4)_3$	% Cu complexed with chelate	% Zn complexed with chelate	% Mn complexed with chelate
1. Knop 1865	100	-	-	-
2. Penningsfeld North Africa	99.9	-	-	-
3. Penningsfeld Carnations	99.9	-	-	-
4. Gravel culture Japan	-	-	-	-
5. Arnon and Hoagland 1940	87.8	40.3	6.4	0.3
6. Dennisch R. Hoagland	4.0	97.5	97.5	0.1
7. Shive and Robbins 1942	99.9	-	-	-
8. Hacskalyo 1961	4.0	99.3	42.4	0.2
9. Steiner 1961	4.9	99.5	48.8	0.2
10. Cooper 1979	5.5	98.3	22.4	0.1
11. Res. Centre Soil. Cultures	6.9	100	99.2	7.7
12. Naaldwijk cucumber	4.5	96.5	7.8	0

This table shows the precipitated Fe and chelated portions of the micro nutrients in all the standard solutions.

The natural question when reading about standard solutions is: which one is the best one to use? Sadly, I don't think there's a simple answer. There have been multiple studies comparing standard solutions (see this one for an example). What ends up happening most of the time is that, while most of the solutions manage to grow healthy crops, one of the solutions happens to be more fit to the idiosyncrasies of the study because its conditions are better aligned with those that the authors developed the solutions under. A study revealing a solution to be better than another to grow plants under a given set of conditions does not imply that this solution will be the best one for all plants under all conditions. For this reason, the optimization of nutrient solutions to particular conditions using tissue analysis is still pursued in order to maximize yields.

My advice would be to view the above solutions as well researched starting points for your hydroponic crops. These solutions, especially the ones developed after 1940, will do a good basic job growing your plants. If you're interested in

making your own solutions, starting with a solution like the Hoagland, Steiner, or Cooper solutions is a great way to begin making your own nutrients. Once you have a basic standard solution working for you, you can then tweak it to maximize your yield and improve your crop's quality.

The stability of metal chelates

When you get introduced to hydroponics and nutrient solution chemistry, one of the first concepts that you learn is chelation. A chelate is a molecule formed by a metallic ion and a chelating agent – which is also referred to as a ligand – where the metal ion is wrapped around very tightly by this ligand. The job of the chelating agent is to keep the heavy metal ion shielded from the environment, allowing it to exist in solution without forming potentially insoluble compounds that will take it out of the nutrient solution. However, these chelates can be unstable or too stable, both of which can hinder the availability of the nutrient to plants. In this post, we're going to talk about what determines the stability of a metal chelate and how you can know if a given chelate will be able to fulfill its job in a hydroponic environment.

$$Kb = \frac{|ML|}{(|M| \times |L|)}$$

A simplified view of the chemical equilibrium formed |M| refers to the concentration of the free metallic ion, |L| the ligand concentration and |ML| the chelate concentration. Charges are omitted for simplicity.

Since chelates are formed by the reaction of a metallic ion – most commonly a cation – which a ligand, a chemical equilibrium is established between the free metallic ion, the ligand, and the chelate. Every second, there are lots of chelate molecules being formed from reactions between metallic ions and ligands, and free metallic ions and ligands are being formed from the disassembly of the chelate. The process is in equilibrium when the rates of assembly and disassembly are the same. The equilibrium constant – also known as the stability constant or Kb – tells us how displaced this equilibrium is towards the product (in this case the chelate). When the Kb value is large, the concentration of the chelate at equilibrium is very large, while when Kb is small, the opposite is true. Since these numbers are usually very large for chelates, we express them as pKb which is -Log(Kb). These constants depend on temperature, but their values are independent of other chemical reactions. However, things like pH can affect the concentration of ligand or metal cation, which can affect the concentration of chelate, since the equilibrium constant's value remains the same.

	Al(III)	Ba	Ca	Co(II)	Cu	Fe(II)	Fe(III)	Hg	Mg	Mn	Ni	Sr	Zn
Acetic acid		0.39	0.53	2.24				3.7d	0.51		0.74	0.43	1.03
Adenine													
Adipic acid		1.92	2.19		3.35								
ADP		2.36	2.82	3.68	5.9				3.11	3.54	4.5	2.5	4.28
Alanine		0.8	1.24	4.82	8.18					3.24	5.96	0.73	5.16
b-Alanine					7.13						4.63		4
Albumin			2.2										
Arginine						3.2				2			
Ascorbic acid			0.19									0.35	
Asparagine			0									0.43	
Aspartic acid		1.14	1.16	5.9	8.57				2.43	3.74	7.12	1.48	2.9
ATP		3.29	3.6	4.62	6.13				4	3.98	5.02	3.03	4.25
Benzoic acid					1.6						0.9		0.9
n-Butyric acid		0.31	0.51		2.14				0.53			0.36	1

Casein			2.23										
Citraconic acid			1.3									1.3	
Citric acid		2.3	3.5	4.4	6.1	3.2	11.85	10.9d	2.8	3.2	4.8	2.8	4.5
Cysteine				9.3	19.2	6.2		14.4d	< 4	4.1	10.4		9.8
Dehydracetic acid					5.6						4.1		
Desferri-ferrichrysin							29.9						
Desferri-ferrichrome							29						
Desferri-ferrioxamin E				11.8	13.7		32.5				12.2		12
3,4-Dihydroxybenzoic acid			3.71	7.96	12.8				5.67	7.22	8.27		8.91
Dimethylglyoxime					11.9						14.6		7.7
O,O-Dimethylpurpurogallin			4.5	6.6	9.2				4.9		6.7		6.8
EDTA	16.13	7.78	10.7	16.21	18.8	14.3	25.7	21.5d	8.69	13.6	18.6	8.63	16.5
Formic acid		0.6	0.8		1.98		3.1					0.66	0.6
Fumaric acid		1.59	2		2.51					0.99		0.54	
Globulin			2.32										
Gluconic acid		0.95	1.21		18.3				0.7			1	1.7
Glutamic acid		1.28	1.43	5.06	7.85	4.6			1.9	3.3	5.9	1.37	5.45
Glutaric acid		2.04	1.06		2.4				1.08			0.6	1.6
Glyceric acid		0.80b	1.18						0.86			0.89	1.8
Glycine		0.77	1.43	5.23	8.22	4.3	10	10.3	3.45	3.2	6.1	0.91	5.16
Glycolic acid		0.66	1.11	1.6	2.81		4.7		0.92			0.8	1.92
Glycylglycine			1.24	3	6.7	2.62	9.1		1.34	2.19	4.18		3.91
Glycylsarcosine				3.91	6.5					2.29	4.44		
Guanosine				3.2	6	4.3			3		3.8		4.6
Histamine				5.16	9.55	9.6	3.72				6.88		5.96
Histidine				7.3	10.6	5.89	4			3.58	8.69		6.63
b-Hydroxybutyric		0.43	0.6						0.6			0.47	1.06
3-Hydroxyflavone				9.91	13.2								9.7
Inosine				2.6	5	3					3.3		
Inosine triphosphate			3.76	4.74					4.04	4.57			
Iron-free ferrichrome							24.6						
Isovaleric acid			0.2		2.08								
Itaconic acid			1.2		2.8						1.8	0.96	1.9
Kojic acid	7.7		2.5	7.11	6.6		9.2		3		7.4		4.9
Lactic acid		0.55	1.07	1.89	3.02		6.4		0.93	1.19	2.21	0.7	1.86
Leucine				4.49	7	3.42	9.9			2.15	5.58		4.92
Lysine							4.5			2.18			
Maleic acid		2.26	2.43		3.9					1.68	2	1.1	2
Malic acid		1.3	1.8		3.4				1.55	2.24		1.45	2.8
Methionine						3.24	9.1				5.77		4.38
Methylsalicylate					5.9		9.77						
NTA	>10	4.82	6.41	10.6	12.7	8.84	15.87		5.41	7.44	11.3	4.98	10.45
Orotic acid				6.39c							6.82		6.42
Ornithine				4.02	6.9	3.09	8.7			<2	4.85		4.1
Oxalic acid	7.26	2.31	3	4.7	6.3	>4.7	9.4		2.55	3.9	5.16	2.54	4.9
b-Phenylalanine					7.74	3.26	8.9						
Pimelic acid										1.08			
Pivalic acid			0.55		2.19								

Polyphosphate			3		3.5	3			3.2	5.5	3		2.5
Proline						4.07	10			3.34			
Propionic acid		0.34	0.5		2.2		3.45		0.54			0.43	1.01
Purine					6.9						4.88		
Pyrophosphate			5		6.7		22.2		5.7		5.8		8.7
Pyruvic acid			0.8		2.2								
Riboflavin				3.9	<6					3.4	4.1		<4
Salicylaldehyde				4.67	7.4	4.22	8.7		3.69	3.73	5.22		4.5
Salicylic acid	14.11			6.72	10.6	6.55	16.35		4.7	2.7	6.95		6.85
Sarcosine				4.34	7.83	3.52	9.7				5.41		
Serine			1.43			3.43	9.2				5.44		
Succinic acid		1.57	1.2	2.08	3.3		7.49		1.2	2.11	2.36	0.9	1.78
(+)-Tartaric acid		1.95	1.8		3.2		7.49		1.36		3.78	1.94	2.68
Tetrametaphosphate		4.9	5.2		3.18				5.17		4.95	2.8	
Threonine						3.3	8.6						
Trimetaphosphate			2.5		1.55				1.11	3.57	3.22	1.95	
Triphosphate		6.3	6.5		9.8				5.8			3.8	9.7
Tryptophan							9						
Uridine diphosphate									3.17				
Uridine triphosphate			3.71	4.55					4.02	4.78			
n-Valeric acid		0.2	0.3		2.12								
Valine					7.92	3.39	9.6			2.84	5.37		5
Xanthosine				2.8	3.4	<2					3		2.4

This table was originally present in a website that no longer exists. The data is taken from the NIST reference of heavy metal complexes.

The table above shows you the pKb values for different metal ions and different ligands or chelating agents. Since the pKb scale is logarithmic, a difference of 1 indicates an order of magnitude higher stability. You can also find additional references to other stability constants in this link. These constants allow us to predict which chelates will be formed if different metallic cations and ligands are present. Let’s say we have a solution that contains Ca2+ and Fe3+ and we add a small amount of sodium citrate, what will happen? Since the constant for Ca2+ is 3.5 but that of Fe3+ is 11.85, citrate will chelate around 1 billion Fe3+ ions for every Ca2+ ion it chelates. In practice, this means that all the Fe3+ that can be chelated will be, while Ca2+ will remain as a free metallic ion. However, if we have Fe^{2+} instead of Fe^{3+} then Fe^{2+} has a constant of only 3.2, which means that one molecule of Fe^{2+}

will be chelated for every 3 of Ca^{2+}, meaning we will have around 25% of all the chelate formed as a chelate formed by Fe^{2+} and 75% as a chelate formed by Ca^{2+}.

We can see in this manner how chelating only one heavy metal can lead to problems. Imagine that you purchase Iron EDTA and add it to your nutrient solution, but you have added Manganese from Manganese sulfate. Upon addition, the FeEDTA chelate will disassemble to generate as much Fe^{2+} and free EDTA as dictated by the equilibrium constant and the free EDTA will then get into equilibria with all the other heavy metals, since the constant with Mn is 13.6 and that of Fe is 14.3 the ligand will redistribute itself so that it complies with all the chemical equilibria present. This means that for every 7 Fe^{2+} cations that are chelated we will have around 1 Mn^{2+} containing chelate, so you will lose around 14% of the chelated Fe in order to chelate free Manganese. That free Fe^{2+} will be unstable and precipitate out, which will shift the equilibrium and cause us to lose more of the Fe chelate. This is how competing equilibria can lead to the slow but sure depletion of available cations in solution.

With the above references and charts, you should now be able to look into any chelating agent you want to use and determine how good of a choice it is for your solution and what is likely to happen once you put that chelate in. The ligand will chelate different metals in order to comply with all the equilibrium constants, so it is up to you to add enough so that all heavy metals are satisfied or add ligands whose affinity for a given ion is so high that the others are just unable to compete for it, almost regardless of their concentration.