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

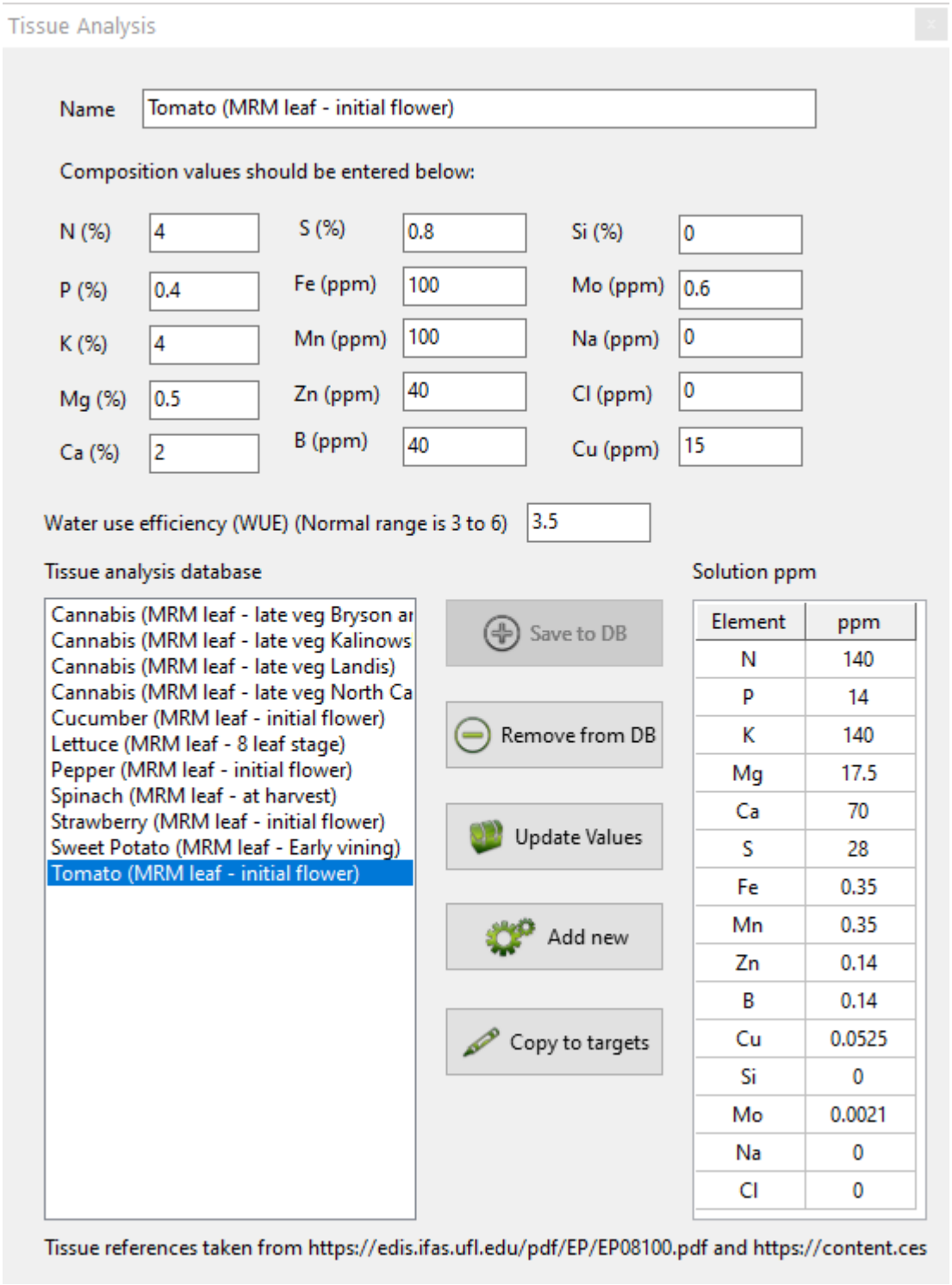
is called Water Use Efficiency (WUE). It is expressed as gram of tissue per liter of water transpired and has values from 3.0 to 6.0. Higher WUE values imply the plant is growing more efficiently, requires less water to grow the same mass of tissue, while a lower WUE implies the plant is less efficient 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

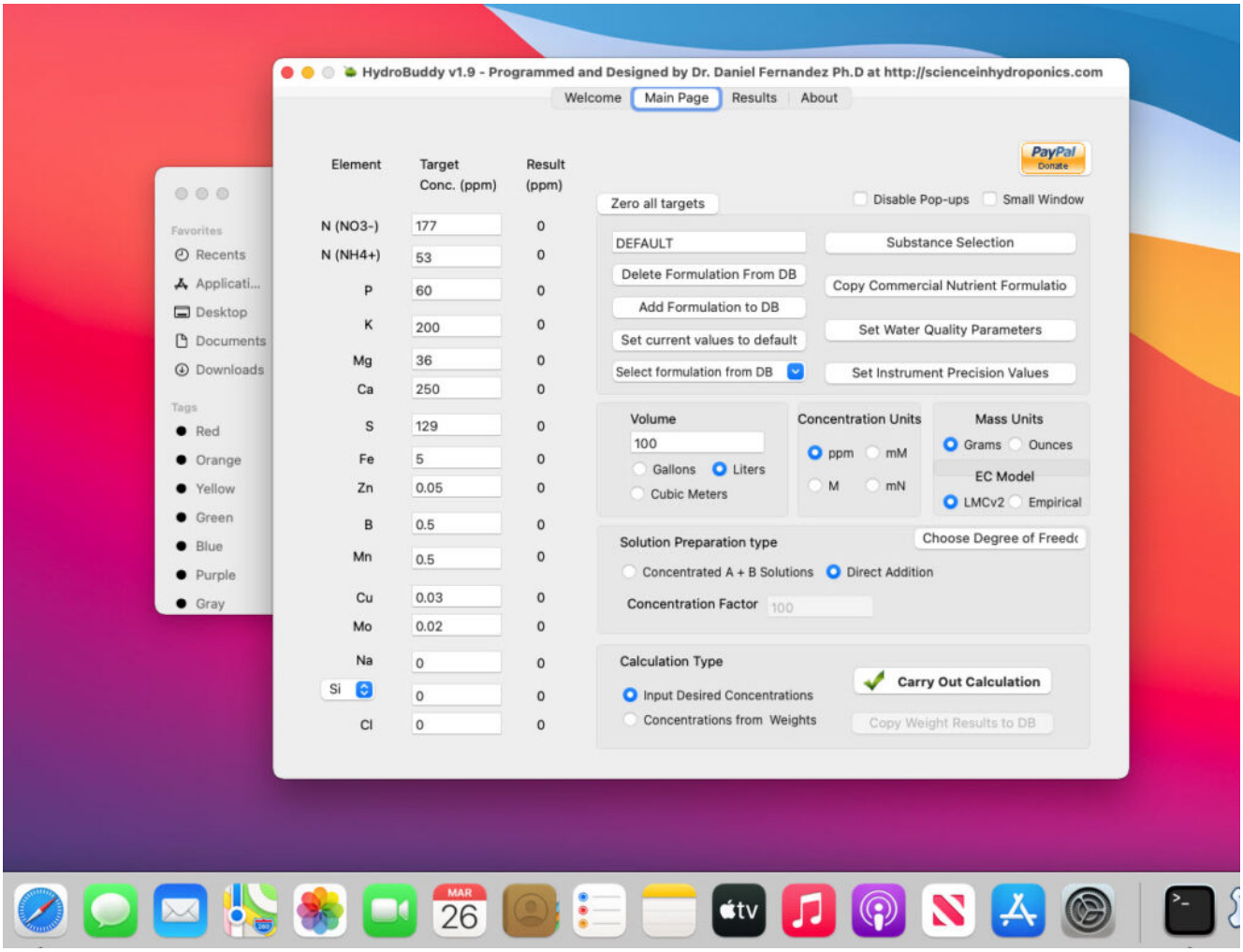
The above solution should fully replace a traditional hydroponic solution, using only OMRI-approved materials. The final concentrations of nutrients should be spot on for the healthy development of most small and large plants. The solution will also contain a lot of microbes and bio-stimulants, which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

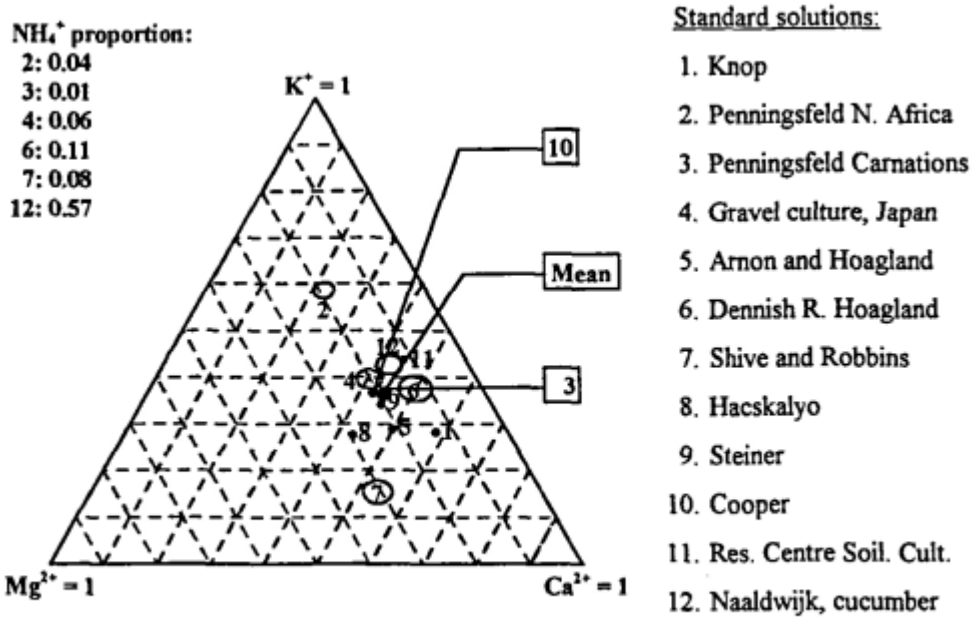


FIGURE 1. Cation composition of the standard solutions.

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

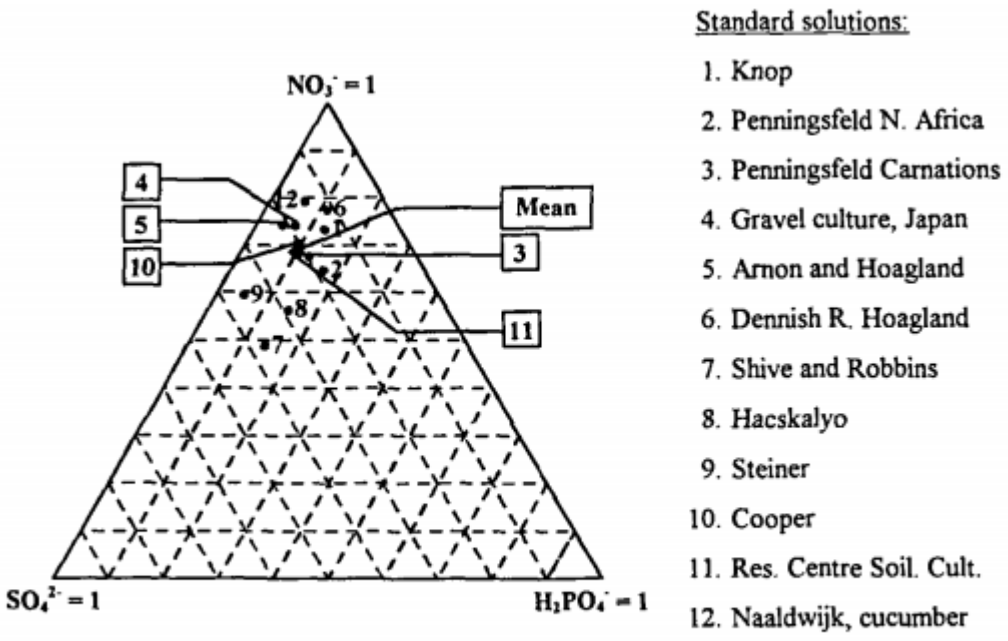


FIGURE 2. Anion composition of the standard solutions.

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+}

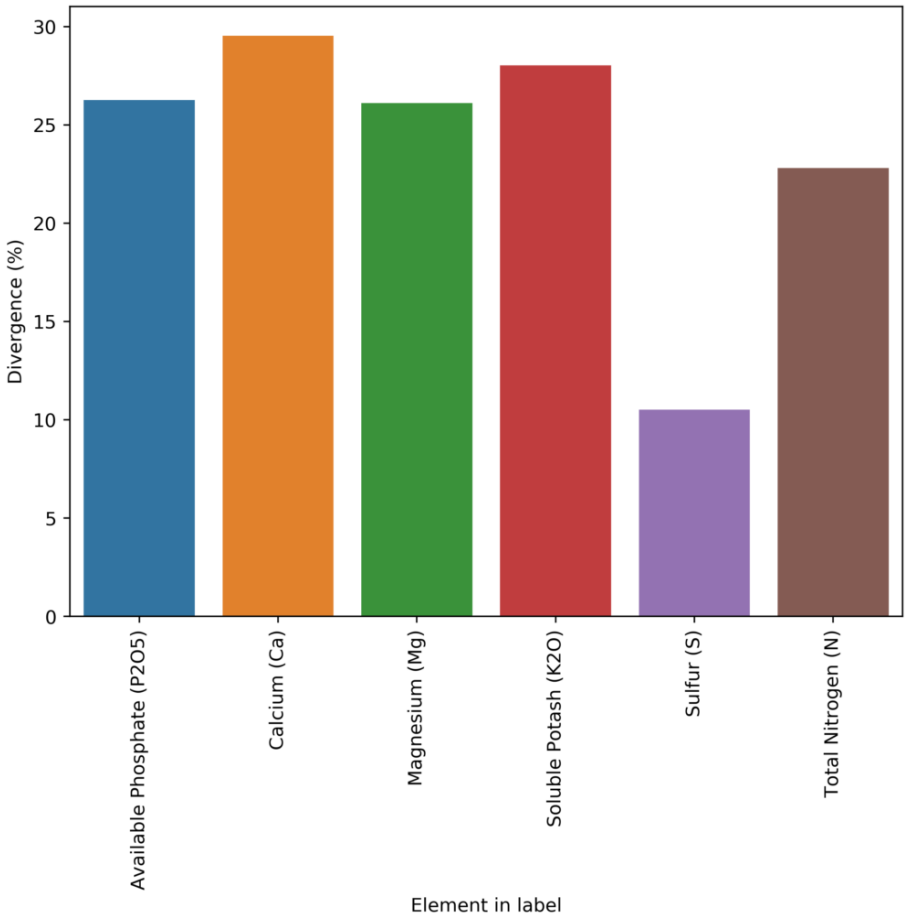
will be chelated for every 3 of Ca^{2+}, meaning we will have around 25% of all the chelate formed as a chelate formed by Fe^{2+} and 75% as a chelate formed by Ca^{2+}.

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.

Differences between labels and actual composition values in commercial hydroponic fertilizers

Whenever I am hired to duplicate a company’s fertilizer regime based on commercial products, I always emphasize that I cannot use the labels of the products as a reference because of how misleading these labels can be. A fertilizer company only needs to tell you the minimum amount of each element it guarantees there is in the product, but it does not have to tell you the exact amount. For example, a company might tell you their fertilizer is 2% N, while it is in reality 3%. If you tried to reproduce the formulation by what’s on the label you would end up with substantially less N, which would make your mix perform very differently. This is why lab analysis of the actual bottles is necessary to determine what needs to be done to reproduce the formulations.

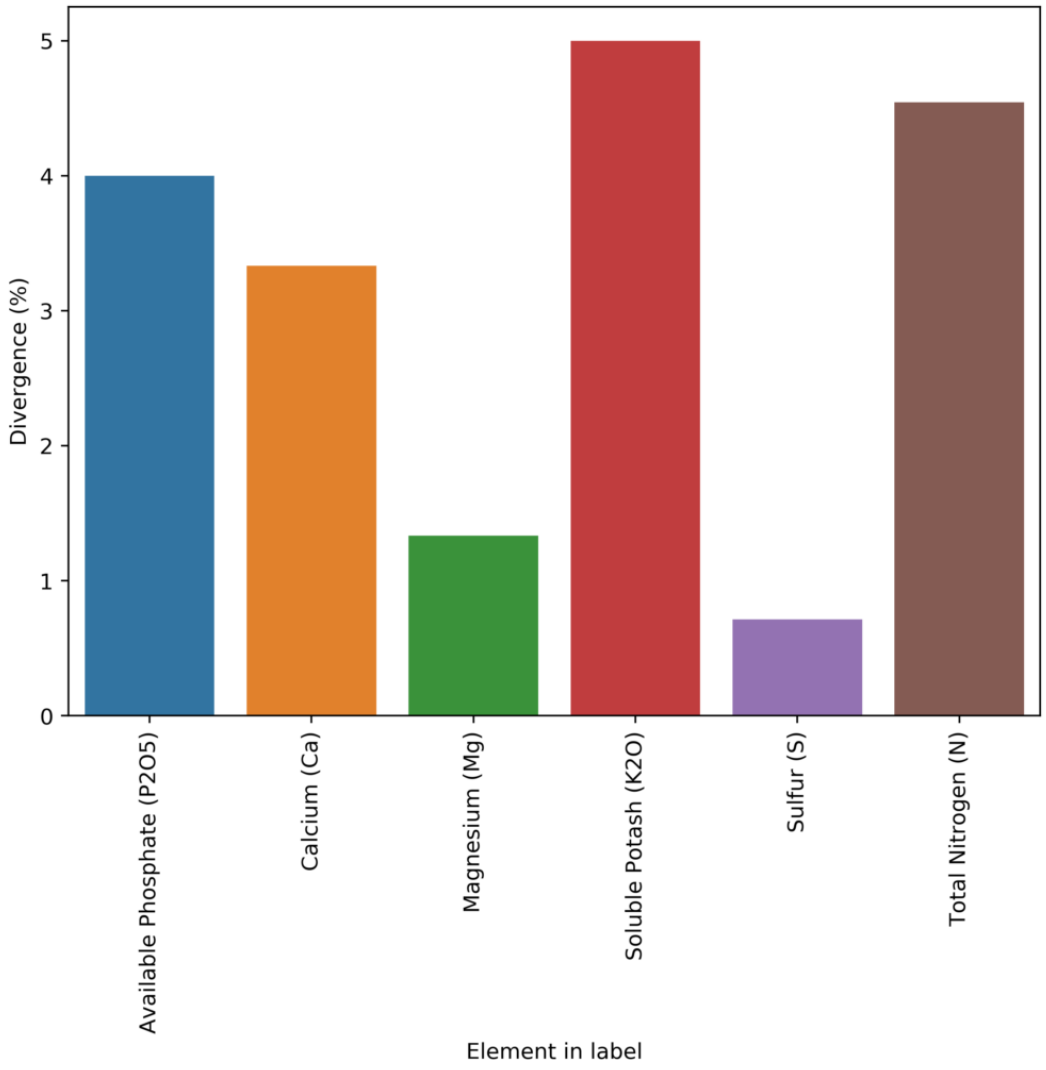


Average deviation from the reported composition on the label compared with lab analysis.

How bad is this problem though? Are companies just under-reporting by 1-5% in order to ensure they are always compliant with the minimum guaranteed amount accounting for manufacturing errors or are they underreporting substantially in order to ensure all reverse engineering attempts based on the labels fail miserably? I have a lot of information about this from my experience with customers – which is why I know the problem is pretty bad – but I am not able to publicly share any of it, as these lab tests are under non-disclosure agreements with them. However, I recently found a website from the Oregon government (see here), where they share all the chemical analysis of fertilizers they have done in the past as well as whatever is claimed on labels.

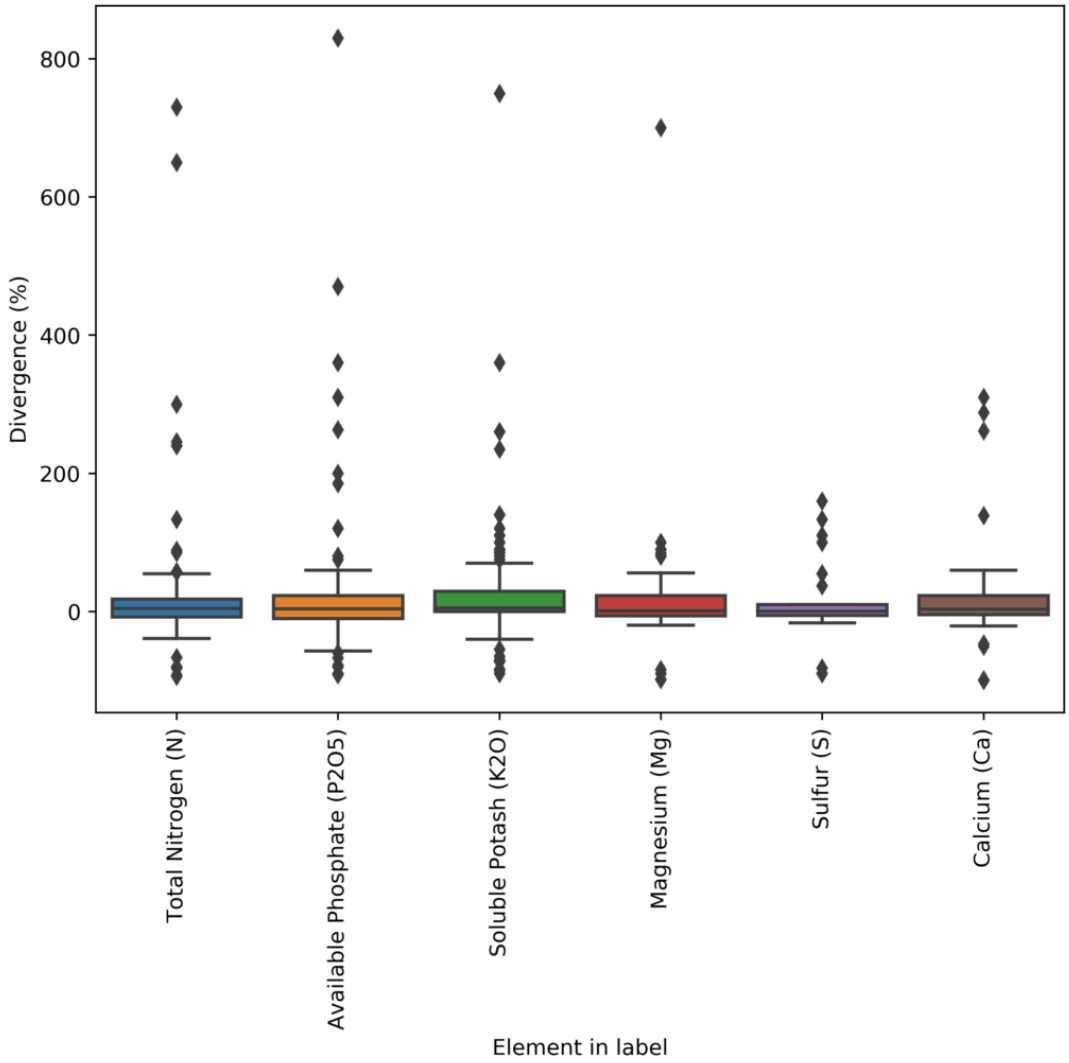
The Oregon database is available in pdf form, reason why I had to develop a couple of custom programming tools to process all the information and put it into a readable database. So far I

have only processed the fertilizers that were registered in 2015, but I am going to process all the fertilizers available in their database up until 2018 (the last year when this report was uploaded). However, you can already see patterns emerging for just the 2015 data. That year there were 245 fertilizers tested, from which 213 contained N, P, K, Ca, S or Mg. If we compare the lab results for these elements with the results from the lab analysis, we can calculate the average deviation for them, which you can see above. As you can see, companies will include, on average, 20%+ of what the labels say they contain. This is way more of a deviation than what you would expect to cover manufacturing variations (which are expected to be <10% in a well-designed process) so this is definitely an effort to prevent reverse engineering.



Median divergence between compositions derived from labels and

lab analyses.



Boxplot of the divergences between compositions derived from labels and lab analyses.

Furthermore, the deviations are by no means homogeneous in the database. The above graphs showing the box plot and median deviation values, show us that most people will actually be deviated by less than 5% from their label requirements, but others will be very largely deviated, with errors that can be in the 100%+ deviation from their reported concentration. In many cases, companies also have negative deviations, which implies that the variance of their manufacturing process was either unaccounted for or there was a big issue in the manufacturing process (for example they forgot to add the chemical containing the element). These people would be in violation of the guaranteed analysis rules and would be fined and their product registrations could be removed.

With this information, we can say that most people try to report things within what would be considered reasonable if the label is to remain accurate (deviations in the 1-5% range) to account for their manufacturing issues but many companies will choose to drift heavily for this and report values that are completely misleading relative to the labels. These companies are often the ones that are most widely used as they are the ones who want to protect themselves from reverse engineering most aggressively.

Take for example General Hydroponics (GH). *Their FloraGro product is registered with an available phosphate of 1%, while the actual value in the product is 1.3%, this is a 30% deviation, far above the median of the industry.* They will also not just underreport everything by the same amount – because then your formulation would perfectly match when you matched their target EC – but they will heavily underreport some elements and be accurate for others. In this same Floragro product, the K_2O is labeled as 6% and the lab analysis is 5.9%, meaning that they reported the value of K pretty accurately. However, by underreporting some but not others, they guarantee that you will skew your elemental ratios by a big margin if you try to reverse engineer the label, which will make your nutrients work very differently compared to their bottles.

As you can see, you just cannot trust fertilizer labels. Although most of the smaller companies will seek to provide accurate labels within what is possible due to manufacturing differences, big companies will often engineer their reporting to make it as hard as possible for reverse engineering of the labels to be an effective tactic to copy them. *If you want to ever copy a commercial nutrient formulation, make sure you perform a lab analysis so that you know what you will be copying and never, ever, rely solely on the labels*. I will continue working on this dataset, adding the remaining fertilizers, and I will expand my analyses to include

micronutrients, which are covered by Oregon government tests.

Five common mistakes people make when formulating hydroponic nutrients

It is not very difficult to create a basic DIY hydroponic formulation; the raw salts are available at a very low cost, and the target concentrations for the different nutrients can be found online. My nutrient calculator – HydroBuddy – contains large amounts of pre-made formulations in its database that you can use as a base for your first custom hydroponic endeavors. However, there are some common mistakes that are made when formulating hydroponic nutrients that can seriously hurt your chances of success when creating a hydroponic recipe of your own. In this post I will be going through the 5 mistakes I see most often and tell you why these can seriously hurt your chances of success.

Failing to account for the water that will be used. A very common mistake when formulating nutrients is to ignore the composition of the water that you will be using and how your hydroponic formulation needs to account for that. If your water contains a lot of calcium or magnesium then you will need to adjust your formulation to use less of these nutrients. It is also important not to trust an analysis report from your water company but to do a water analysis yourself, since water analysis reports from your water company might not be up to date or might not cover the exact water source your water is coming from. It is also important to do several analyses per year in order to account for variations

in the water composition due to temperature (which can be big). Other substances, such as carbonates and silicates also need to be taken into account in your formulation as these will affect the pH and chemical behavior of your hydroponic solution.

Failing to account for substances needed to adjust the pH of the hydroponic solution. When a hydroponic solution is prepared, the pH of the solution will often need to be adjusted to a pH that is within an acceptable range in hydroponics (often 5.8-6.2). This is commonly achieved by adding acid since when tap/well water is used, a substantial amount of carbonates and/or silicates will need to be neutralized. Depending on the salt choices made for the recipe, adjustments could still be needed even if RO water is used. Since these adjustments most commonly use phosphoric acid, not accounting for them can often cause solutions to become very P rich with time, causing problems with the absorption of other nutrients, especially Zn and Cu. A nutrient formulation should account for the pH corrections that will be required and properly adjust the concentration of nutrients so that they will reach the proper targets considering these additions.

Iron is chelated but manganese is not. It is quite common in hydroponics for people to formulate nutrients where Fe is chelated with EDTA and/or DTPA but manganese sources are not chelated at all, often added from sulfates. Since manganese has a high affinity for these chelating agents as well, it will take some of these chelating agents from the Fe and then cause Fe phosphates to precipitate in concentrated solutions. To avoid this problem, many nutrient solutions in A/B configurations that do not chelate their Mn will have the Fe in the A solution and then the other micronutrients in the B solution. This can be problematic as it implies the Fe/other micro ratios will change if different stages with different A/B proportions are used through the crop cycle. In order to avoid this issue, always make sure all the micronutrients are chelated.

Not properly considering the ammonium/nitrate ratio. Nitrogen coming from nitrate and nitrogen coming from ammonium are completely different chemically and absorbed very differently by plants. While plants can live with solutions with concentrations of nitrogen coming from nitrate as high as 200-250ppm, they will face substantial toxicity issues with solutions that contain ammonium at only a fraction of this concentration. It is therefore quite important to ensure that you're adding the proper sources of nitrogen and that the ratio of ammonium to nitrate is in the ideal range for the plants that you're growing. When in doubt, plants can survive quite well with only nitrogen from nitrate, so you can completely eliminate any additional sources of ammonium. Note that urea, provides nitrogen that is converted to nitrogen from ammonium, so avoid using urea as a fertilizer in hydroponic.

Not considering the media composition and contributions. When growing in hydroponic systems, the media can play a significant role in providing nutrients to the hydroponic crop and different media types will provide nutrients very

differently. A saturated media extract (SME) analysis will give you an idea of what the media can contribute and you can therefore adjust your nutrient solution to account for some of the things that the media will be putting into the solution. There are sadly no broad rules of thumb for this as the contributions from the media will depend on how the media was pretreated and how/if it was amended. It will often be the case that untreated coco will require formulations with significantly lower K, while buffered/treated coco might not require this. Some peat moss providers also heavily amend their media with dolomite/limestone, which substantially changes Ca/Mg requirements, as the root system

---

Practical use of ion selective electrodes in hydroponics

The achievement of adequate ion concentrations in nutrient solutions, media and plant tissue is key to success in hydroponics. It is therefore important to measure them, so that proper values can be maintained. Up until now, this has been mostly achieved with the use of external lab testing but electrochemical developments made during the past 10 years have made the production of ion selective electrodes with high enough selectivity coefficients viable at a large scale. This means that it is now possible to obtain sensors that yield accurate enough measurements of nitrate, potassium and calcium concentrations, which allows for routine monitoring of these values without having to worry too much about complicated electrode calibration that accounts for selectivity issues. In today’s article I am going to be talking about these

electrodes and how they can be used in hydroponic crops.

A potassium ion selective electrode manufactured by Horiba

An ion selective electrode is an electrochemical device that is sensitive to the concentration of a single ion in solution. This is commonly achieved by coating an electrode with a molecule that can uniquely accommodate that ion, so that the potential measured across that electrode and a reference electrode will change proportionally to the concentration of that ion. A pH electrode achieves this effect with glass – a pH electrode is basically an H_3O^+ ion selective electrode – while to sense other ions the use of other molecules is required. For example Valinomycin – a molecule originally developed as an anti-biotic – is able to accommodate K^+ ions very selectively, reason why an electrode coated with a Valinomycin containing membrane will be sensitive to changes in K^+ concentration.

The issue with using these electrodes in hydroponics has

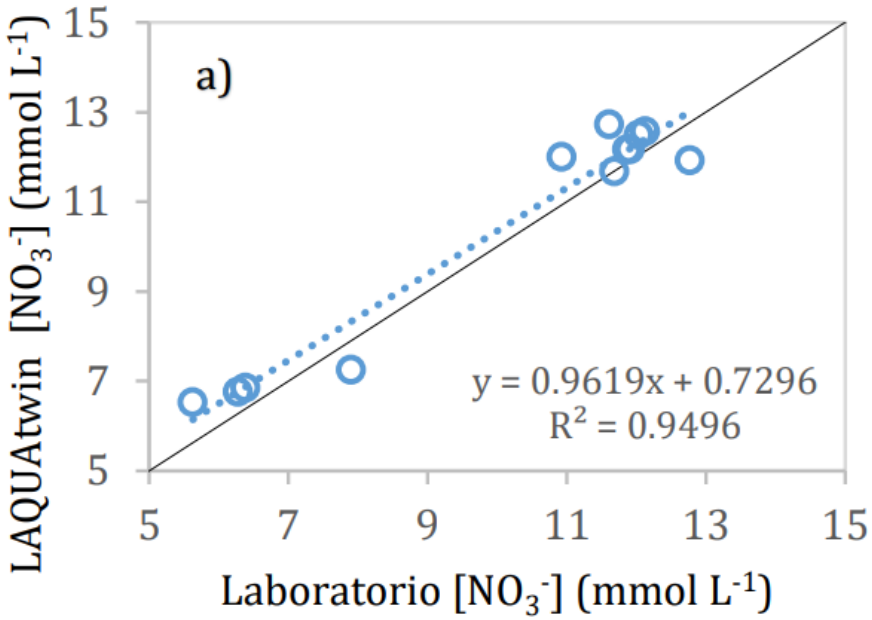
always been two fold. First, the electrodes were commonly very expensive (thousands of dollars per electrode) and second, the selectivity of the electrodes was limited enough that the concentrations of other ions in hydroponic solutions caused substantial interference. This meant that accurate use in hydroponics required someone with analytical chemistry training that would calibrate the electrodes to variations in a single ion against a more complicated ionic background, a process which greatly limited the applicability of the technology. However, companies like Horiba have now developed electrodes that overcome both of these issues, with electrodes that have high selectivity coupled with very attractive prices. You can see Horiba's ion selective electrodes for potassium, calcium and nitrate in the links below. These electrodes are very simple to use and come with solutions to perform 2 point calibrations which are good enough given their high selectivity.

Note that Horiba is *not* sponsoring this content, but the links below are amazon affiliate links that will help support this blog at no extra cost to you, if you decide to purchase them.

- Potassium selective electrode
- Nitrate selective electrode
- Calcium selective electrode

Are these electrodes good enough for hydroponics? The answer is, yes! This independent Spanish research thesis looked at the use of two different brands of ion selective electrode for the determination of potassium, calcium and nitrate in hydroponic solutions. Their results show that the Horiba probes achieve good accuracy in the determination of all of these ions, correlating very well with lab measurements of the same nutrient solutions. With these probes you can therefore monitor the concentrations of K, Ca and N as nitrate as a function of time, giving you substantial information about the accuracy of your solution preparations and – probably most importantly in the case of Ca – information about how your

water supply calcium content is changing through time, which can be very important if you're using tap water to prepare your hydroponic solutions. The determinations are instantaneous, which gives you the ability to quickly react, without the need to wait for a long time for lab analysis to come back.



Results for lab measured Vs probe measured nitrate concentrations for hydroponic nutrient solutions using the Horiba probes.

Another very interesting use of these ion selective electrodes is for the monitoring of plant sap to measure nutrient concentrations in tissue. This can be achieved by collecting petiole tissue from mature leaves to perform an extraction – using a garlic press – which then generates sap that can be measured directly using the electrodes. This gives you the ability to perform a lot of tissue measurements, allowing you not only to look at nutrient concentrations of a single plant, but to monitor tissue concentrations from different plants or even different zones in the same plant. You can obtain results from the analysis right away, which allows for much quicker actions to be taken if required. Horiba shows some examples of how this sap analysis can be carried out here.

Although the information given by the above electrodes is not

perfect, it has the advantage of being instantaneous and known to correlate very well with lab results measured using ICP. The ability to carry out 10x more analysis and to monitor these three ions way more closely in tissue, nutrient solutions, run-off, foliar sprays, etc, opens up a lot of ways to improve crop nutrition and to see problems coming way before they become major issues. Imagine being able to monitor the K, Ca and nitrate concentration in your solutions and plant tissue daily, instead of once a week, month or even sometimes even only once per crop cycle, for a fraction of the cost.