A cost analysis of fertilizers for hydroponic/soilless growing in 2022

Why fertilizer costs matter

Fertilizer can be one of the largest expenses of a hydroponic growing facility. This is especially true when boutique fertilizers are used, instead of large scale commodity fertilizers. The use of non-recirculating systems with high nutrient concentrations also contributes heavily to high cost fertilizer usage. A medium scale growing facility working with boutique fertilizers can in some cases spend 2000-4000 USD per day. Even when using some of the most cost effective solutions, a facility can still spend 4000 USD per day if they use 20,000 gal/day with a nutrient line costing 0.2 USD/gal.

The above is a common combination of raw inputs and a standard blended input

In 2022, the high cost of energy and high inflation have increased raw fertilizer input costs to the highest point of the past decade, making the problem of fertilizer costs even more pressing. This has been specially the case for soluble phosphate fertilizers which have, in some cases, seen costs triple from the start of 2019. This is because soluble phosphates were largely produced in Russia and alternative sources of soluble phosphates had a hard time ramping up capacity at the same cost level as could be previously achieved.

To help people who are growing better assess their costs, I seek to paint a clear picture of the current cost level of commodity and boutique fertilizers as well as the cost levels that can be achieved with preparation of custom solutions.

Price sources

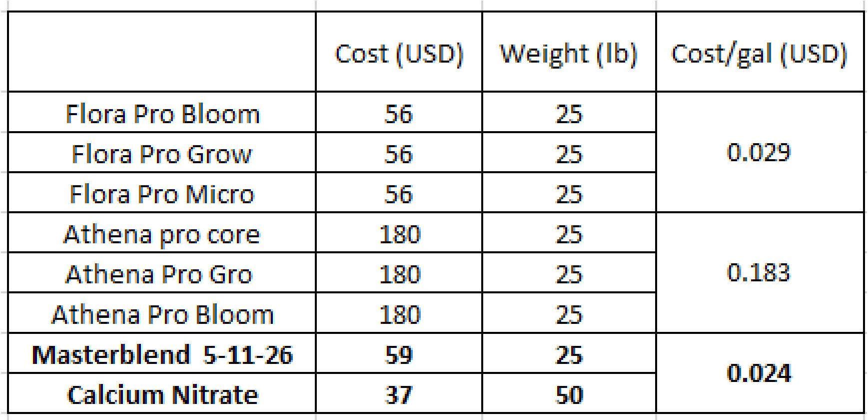
The cost analysis focuses on the US market. The prices I obtained for boutique fertilizers are from google searches where I found the cheapest costs at the highest scale I could find. For commodity fertilizers I used the price points of customhydronutrients.com, which is a trust-worthy website for the purchase of fertilizer inputs. These prices are also accessible from small to large scales, so they do not require large scales to be accessible. Boutique fertilizer companies might offer larger discounts to people who contact them directly to buy large amounts, but I did not use these prices as they are not publicly available.

To make comparisons easier, I will express all costs as costs per final gallon of nutrient solution, when prepared per the directions of the manufacturer or to arrive at formulations with a reasonable composition (formulations that can grow healthy, high yield crops). Please also note that I only considered fertilizers that could be used to prepare concentrated solutions to be used for injection, as these are fundamental to large scale growing operations. I also only considered powdered fertilizers as these offer the lowest cost. Liquid concentrated fertilizers – which are often substantially more expensive – were not considered.

For purposes of keeping the costs as low as possible I also only considered the base products from boutique fertilizer companies and did not consider the costs of any of their additives (line cleaners, boosters, hormones, etc). Shipping costs are also *not* considered here.

Blended fertilizers

The easiest, most accessible fertilizers for most people will be pre-blended fertilizers. Due to the proliferation of the cannabis industry, most of the pre-blended fertilizers that are sold to retail growers will be cannabis-centric and will have a considerably higher price than the blends currently used by the wider hydroponic industry.



	Cost (USD)	Weight (lb)	Cost/gal (USD)
Flora Pro Bloom	56	25	0.029
Flora Pro Grow	56	25	
Flora Pro Micro	56	25	
Athena pro core	180	25	0.183
Athena Pro Gro	180	25	
Athena Pro Bloom	180	25	
Masterblend 5-11-26	**59**	**25**	**0.024**
Calcium Nitrate	**37**	**50**	

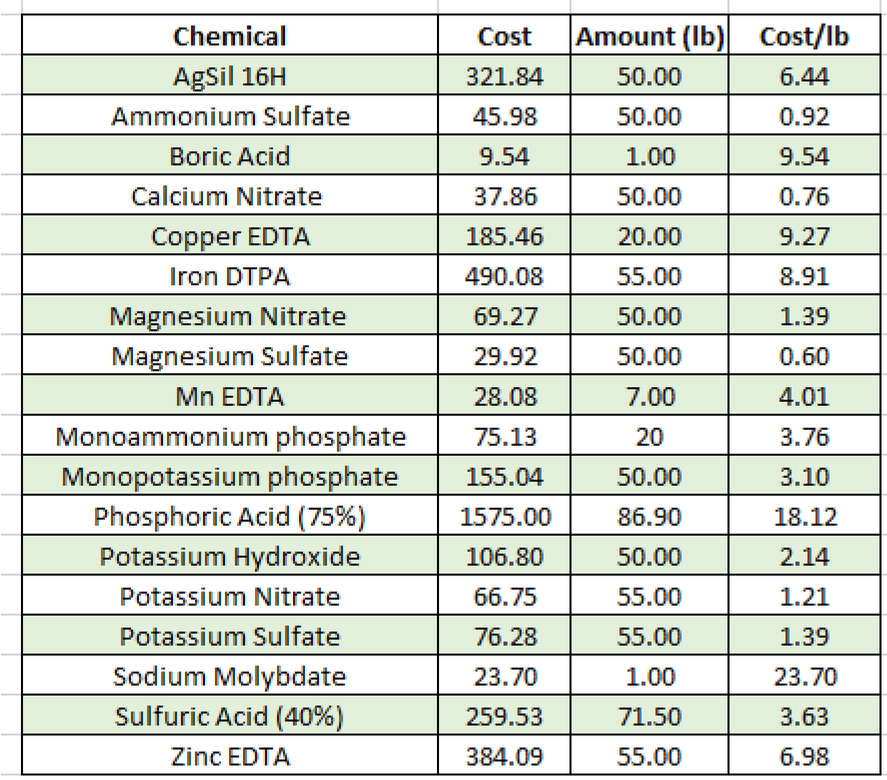
Table comparing a couple of boutique lines with a standard 5-11-26 preparation using a Masterblend product and Calcium nitrate.

The table above shows three representative fertilizer programs for comparison. The Flora Pro series from General Hydroponics was the lowest cost boutique fertilizer I could find, with a total cost of 0.029 USD per gallon at the recommended dosing rates by General Hydroponics. I also put the Athena line for comparison, as they often portray themselves as a low cost option for cannabis companies. Their cost is almost an order of magnitude higher, at 0.183 USD/gal. From this analysis it seems clear that their margins are much higher than those of General Hydroponics although they can be substantially more cost effective than other companies with even more expensive products.

After seeing the above table, it is clear that boutique companies are not price competitive against formulations using traditional blended fertilizers from the agricultural industry. A formulation using Masterblend 5-11-26 and Calcium nitrate, which could be perfectly adequate for the growth of flowering plants during their vegetative stage or purely vegetative plants like basil, has a cost of 0.024 USD/gal. Similar simple approaches using other blended products can be used to achieve a variety of compositions at a similar price tag.

Raw input fertilizers

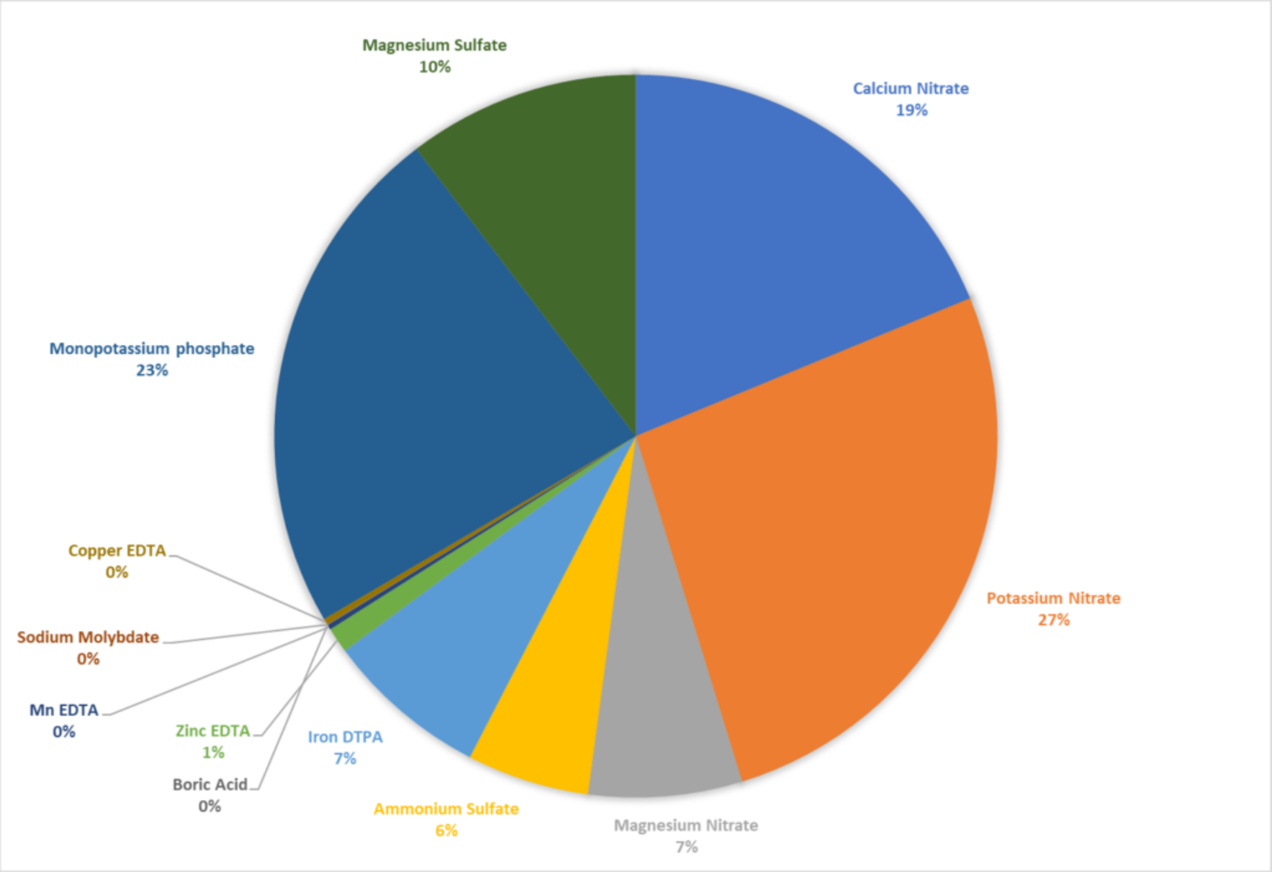
It is also interesting to consider the case of raw fertilizer inputs as this allows us to better think about formulations to reduce cost and also calculate whether making custom fertilizers is worth the expense. The table below shows you some commonly used bulk fertilizer inputs, their cost in USD and the cost per pound of each one of the products.



Chemical	Cost	Amount (lb)	Cost/lb
AgSil 16H	321.84	50.00	6.44
Ammonium Sulfate	45.98	50.00	0.92
Boric Acid	9.54	1.00	9.54
Calcium Nitrate	37.86	50.00	0.76
Copper EDTA	185.46	20.00	9.27
Iron DTPA	490.08	55.00	8.91
Magnesium Nitrate	69.27	50.00	1.39
Magnesium Sulfate	29.92	50.00	0.60
Mn EDTA	28.08	7.00	4.01
Monoammonium phosphate	75.13	20	3.76
Monopotassium phosphate	155.04	50.00	3.10
Phosphoric Acid (75%)	1575.00	86.90	18.12
Potassium Hydroxide	106.80	50.00	2.14
Potassium Nitrate	66.75	55.00	1.21
Potassium Sulfate	76.28	55.00	1.39
Sodium Molybdate	23.70	1.00	23.70
Sulfuric Acid (40%)	259.53	71.50	3.63
Zinc EDTA	384.09	55.00	6.98

Cost and cost per pound of each fertilizer input

Micronutrients are the most expensive per pound, but since they are used at very low amounts, their total cost contribution to fertilizer solutions is often less than 0.002 USD/gal (not counting the iron). The cost of the bulk fertilizers is much more important from a cost impact perspective. From these fertilizers, potassium inputs are often the most expensive. Both potassium nitrate, potassium sulfate and monopotassium phosphate are usually large contributors to the total price of a hydroponic formulation. Soluble silicon amendments, like AgSil16H, are also often large contributors to the overall price of these formulations. The above analysis also shows that Phosphoric acid is a very expensive option for pH adjustments in hydroponics. For this reason – and a few other reasons out of the scope of this post – sulfuric acid should almost always be used.



Cost contribution of bulk fertilizers to a custom hydroponic formulation.

The image above shows you the bulk contributions of all the raw inputs used in a sample custom formulation. The total cost of this formulation is around 0.016 USD/gal. If we supplemented Silicon from AgSil16H, the cost of this formulation would likely increase to close to 0.025-0.03g/gal depending on how much Si we would like to add. You can see here that the highest bulk costs are indeed the monopotassium phosphate and the potassium nitrate, it is unlikely that we would be able to diminish this cost contribution substantially, as this is the true bottom line of the fertilizer industry.

For most of my clients, formulation costs in real life will usually be between 0.01-0.03 USD/gal. The final cost will depend on which bulk discounts are available at scale, which plants the client is growing, what the cost of shipping the fertilizer is and which additional amendments beyond simple raw fertilization we choose to use. Sometimes, by using the nutrients already present in the water, substantial additional savings are possible with custom formulations.

Note that the above raw input analysis does not include the cost of labor to prepare the concentrated nutrients needed for injection. If a worker needs to spend a couple of hours per week mixing 25 gallons of each fertilizer then this, at 20 USD/hour, would likely increase the cost of the fertilizer by around 2-5%. Since workers can often mix batches of concentrated solutions that end up creating thousands of gallons of solution, the labor cost needed to mix fertilizers is often not meaningful relative to the overall cost of the inputs.

Balance between complexity and cost

From the above, it is clear that making your own fertilizer has the lowest cost, even *at a small scale*. However, it does add a substantial level of complexity to an operation and exposes the operation to a variety of potential mistakes dealing with preparation. A careful consideration of the advantages and disadvantages of mixing your fertilizer needs to be made. For large facilities, I believe this to be a no-brainer. At scale, it almost certainly makes sense to mix your own fertilizers.

However, it is true that at a medium scale, a grower might benefit from not doing their own mixing, as this simplifies their operation and allows them to focus on growing great plants while they grow. In this case, you can certainly – regardless of the plant you’re growing – create a formulation based on a widely available agricultural industry blend with perhaps one or two raw inputs, to achieve a highly cost effective formulation.

Of course, there is also an additional cost to fertilizer formulation, which – per the prices charged by myself and other colleagues – might cost you from hundreds to thousands of dollars depending on complexity. If you do not want to incur this cost, then you should bear in mind you will pay a perpetually higher price in your fertilizers, to a company that has done the formulation work for you.

At a large scale, you definitely do not want to go with a formulation that reduces the yield or quality of your plant product, so – if you lack the experience to do these formulations yourself – always make sure to hire someone who knows what they are doing.

In the simplest case, a formulation schedule of an agricultural preblended product – using for example the Masterblend 5-11-26 mentioned above – adjusted to your situation might lower your costs by an order of magnitude from an expensive boutique shop at a minimal increase in complexity and low formulation costs. Of course you can always make your own Masterblend proxy as a first step when you move to fully custom formulations. If it is not possible to use these types of blends – due to for example your water composition – a fully custom formulation will be required.

There is no reason to pay even higher prices

People in the traditional large scale hydroponic industry have been growing at very cost effective fertilizer prices for decades. If you are a small, medium or even large scale grower, there is no reason why your fertilizer costs should be astronomically high. There are no reasons to perpetually pay high margins to fertilizer companies and there is no reason why you shouldn't take advantage of the easiest cost savings that can be achieved with products that are already available to the bulk agricultural industry. Now that the raw fertilizer input costs are even higher, it is more important than ever to go to lower cost methods to achieve your desired hydroponic formulations.

If you want to learn how to make your own fertilizers, then I advice you visit my youtube channel or read my blog articles on making your own fertilizers from raw inputs.

Are you using boutique fertilizers? Are you mixing your own? Please let us know about your experience in the comments below!

How to reuse your coco coir in soilless growing

Why reuse media

Buying new media and spending labor to mix, expand, and even amend it can be a costly process for growing facilities. Dumping media also involves going through a composting process, wasting nutrients that are already present in that media when it is thrown away. However, media in hydroponics serves a mostly structural role and there are no fundamental reasons why media like coco cannot be recycled and used in multiple crop cycles.


Coco coir commonly used as a substrate in soilless agriculture.

By reusing media, a grower can substantially reduce operational costs. This is because the media itself often contains an important amount of surplus nutrition and the roots and other organic components left behind by previous plants can also be used by new crops to sustain their growth. These added decomposing root structures also reduce channeling in the media and help improve its water retention as a function of time. After a media like coco is reused several times, the coco also degrades and becomes finer, further improving water retention.

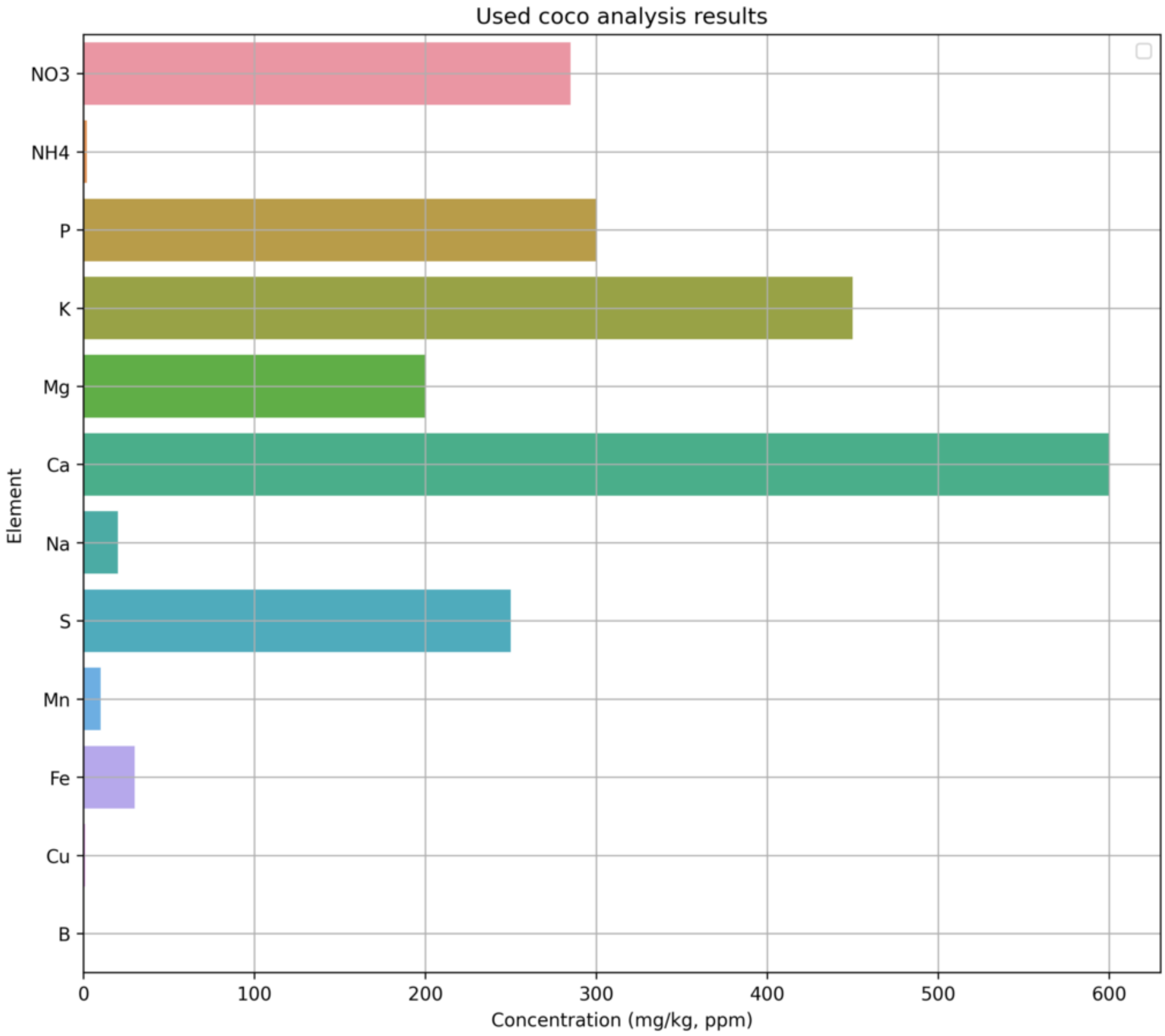
Why media is often not reused

Reusing media is not without peril. When media is pristine, it is more predictable. You know its basic composition and you can feed it the same set of nutrients and hope to obtain very similar results. Nonetheless, after media goes through a growing cycle, its chemical composition changes and the starting point becomes much more variable. This means that a grower needs to somehow adjust nutrition to the changes in composition, which can often make it difficult for the crop to achieve consistent results.

If a grower reuses media but tries to feed as if the media was new, then problems with overaccumulation of nutrients in the media will happen and it will be hard for the grower to obtain reliable results. Reusing media requires a different approach to crop nutrition which scares people away because it strays from what nutrient companies and normal growing practices require. However we will now learn how media is chemically affected by cultivation and how we can take steps to reduce these effects and then successfully reuse it.

Media composition after a normal crop

In traditional coco growing, fertilizer regimes will tend to add a lot of nutrients to the coco through the growing cycle. From these nutrients, sulfates, phosphates, calcium and magnesium will tend to aggressively accumulate in the media while nutrients that are more soluble like nitrate and potassium will tend to accumulate to a lesser extent or be easier to remove.



Analysis of used coco from a tomato crop. This analysis uses a DTAP + ammonium acetate process to extract all nutrients from the media. This media had a runoff pH of 6 with an EC of 3.0 mS/cm.

The above image shows you the analysis results of a coco sample that was used to grow a tomato crop. In this analysis, the media is extracted exhaustively using a chelating agent, to ensure that we can get a good idea of all the cations that are present in the media. The chelating agent overcomes the cation exchange capacity of the media, forcing all the cations out – fundamentally exchanging them for sodium or ammonium – and showing you the limits of what could be extracted from the media by the plant.

In this case, the amount of Ca is so high, that it can fundamentally provide most of the Ca required by a plant through its next growing period. Since most of this Ca is going to be present as calcium sulfate and phosphate, it will only be removed quite slowly from the root zone by leachate. The amount of potassium is also quite high, but this potassium is going to go out of the media quite easily and is only likely to last for a short period of time.

In addition to the above mineral content, coco that is reused will often contain a lot of plant material, roots that remained from the previous crop, so the subsequent reuse of the media needs to incorporate adequate enzymatic treatments to help breakdown these organics and ensure that pathogens are not going to be able to use these sources of carbon as an anchor point to attack our plants.

Steps before the crop ends

Because of the above, one of the first steps we need to carry out if we want to reuse media is to ensure that the media is flushed during the last week of crop usage with plain water, such that we can get most of the highly soluble nutrients out of the media so that we don’t need to deal with those nutrients in our calculations. This will remove most of the nitrogen and potassium from the above analysis, giving us media that is easier to use in our next crop.

In addition to this, we will also be preparing our media for the digestion of the root material. Before the last week of cultivation, we will add pondzyme to our plain water flushing at a rate of 0.1g/gal, such that we can get a good amount of enzymes into our media. We should also add some beneficial microbes, like these probiotics, at 0.25g/gal, so that we can get some microbial life into the media that will help us decompose the roots after the plants that are currently in the media will be removed.

How to manage the new crop

Once the crop ends, we will remove the main root ball from the media. There is no need to make an effort to remove all plant material as this would add a lot of labor costs to media reuse. The media should then be allowed to dry, such that the roots that are left behind can then be easily broken up before new plants are placed in the media. Machines to breakup any roots are ideal, although this can also be done manually and easily once all the root material in the media is dead and the roots lose their capacity to hold their structure together.

Once we have dry coco with the root structures broken up, we can then fill up new bags to reuse this media for our next crop. After doing a lot of media analysis and working with several people reusing media, I have found this method works well. If we performed the flushing steps as instructed before, then we can use the media runoff EC as a way to evaluate the type of nutrition needed.

While the runoff EC remains above *1.5mS/cm*, we feed a solution containing only potassium nitrate and micronutrients (no phosphorus, sulfates, calcium or magnesium) at 2g/gal of KNO_3 + micros. After the runoff EC drops below 1.5mS/cm we return to feeding our normal regime. The idea here is that while the media is above 1.5mS/cm the plant can take all the nutrients it needs from the media, but once the media EC drops below 1.5mS/cm, the media is deprived from these nutrients and we need to provide them again for the plant.

Bear in mind that while the nitrogen content of the above feed seems low (just 73 ppm of N from NO_3) there is additional nitrogen that is coming from the decomposition of the organic materials left in the media, which can supplement the nitrogen needs of the plants. Despite the flushing on the last week, there is always some nitrate left from the previous crop. I have found that this is enough to support the plant until the runoff drops below our 1.5mS/cm threshold. After this point, the plant can be grown with its normal nutrition.

Simple is better

Although you would ideally want to find exactly which nutrients are missing or present after each batch of media and adjust your nutrition such that you can get your plants the ideal nutrient composition every time, this is not cost effective or required in practice to obtain healthy plant growth. A media like coco possesses a good degree of nutrient buffering capacity (due to it's high cation exchange capacity and how much nutrition is accumulated after a crop cycle), so it can provide the plants the nutrition of certain nutrients that they need as long as the nutrients that are most easily leached (K and N) are provided to some degree.

The above strategy is simple and can achieve good results for most large crops that are grown using ample nutrients within their normal nutrient formulations. It is true that this might not work for absolutely all cases (or might need some adjustments depending on media volumes) but I've found out it is a great strategy that avoids high analysis costs and the need to create very custom nutrient solutions.

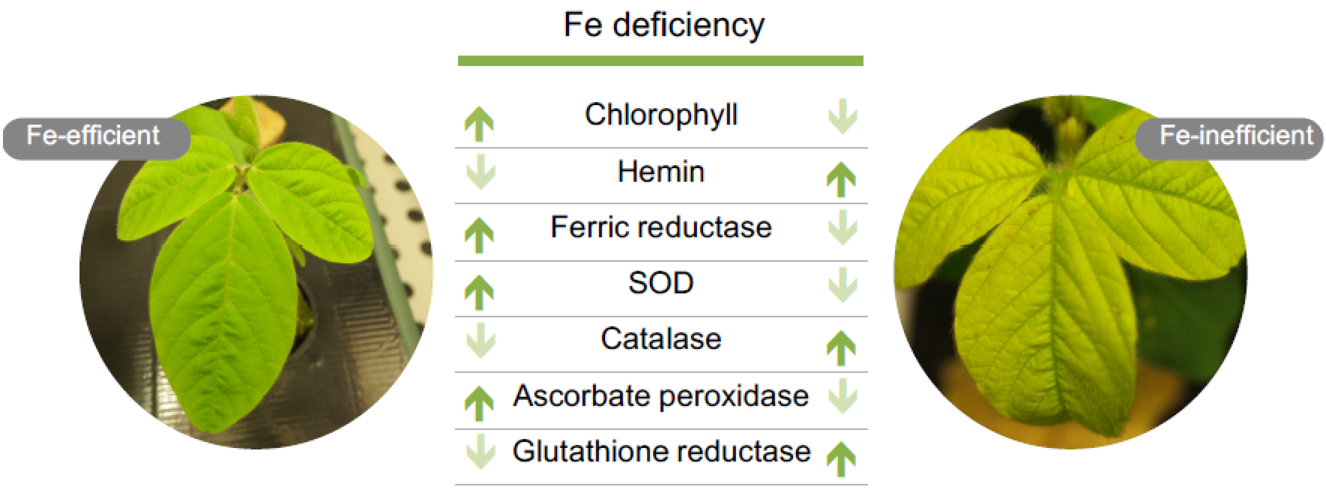
Do you reuse your coco? Let us know which strategy you use and what you think about my strategy!

Are Iron chelates of

humic/fulvic acids better or worse than synthetics?

Why Fe nutrition is problematic

Plants need substantial amounts of iron to thrive. However, iron is a finicky element, and will react with many substances to form solids that are unavailable for plant uptake. This is a specially common process under high pH, where iron can form insoluble carbonates, hydroxides, oxides, phosphates and even silicates. For this reason, plant scientists have – for the better part of the last 100 years – looked for ways to make Fe more available to plants, while preventing the need for strategies that aim to lower the pH of the soil, which can be very costly when large amounts of soil need to be amended.



The image above is taken from [this paper]() on Fe deficiencies.

In hydroponics, the situation is not much better. While we can add as much Fe as we want to the hydroponic solution, the above processes still happen and the use of simple Fe salts (such as iron nitrate or iron sulfate) can lead to Fe deficiencies as the iron falls out of solution. This can happen quickly in root zones where plants aggressively increase the pH of solutions through heavy nitrate uptake.

For a better understanding of the basics of soil interactions with microbes, plants and the overall Fe cycle, I suggest reading this review (6).

Synthetic chelates to the rescue

The above problems were alleviated by the introduction of synthetic iron chelates in the mid 20th century. The chelating agents are organic moieties that can wrap around the naked metal ions, binding to their coordination sites. This kills their reactivity and ensures that they do not react with any of the substances that would cause them to become unavailable to plants. Plants can directly uptake the chelates, take the iron and push the chelate back into solution, or they can destroy the chelate and use its carbon within their metabolism.

Chelates can bind Fe very strongly though, and this is not desirable for some plants that do not have the enzymatic machinery required to open these “molecular cages”. Studies with monocots (1) – which are grasses – have often found that these plants respond poorly to Fe supplementation with molecules like Fe(EDDHA), a very powerful chelate. So powerful in fact, that not even the plants can get the Fe out. For these plants, weaker chelates often offer better results, even at higher pH values.

Another problem is that many of the synthetic chelates are not very good at high pH values. When the pH reaches values higher than 7.5, chelates like EDTA and DTPA can have problems competing with the much more strongly insoluble salts that form at these pH values. The chelated forms are always in equilibrium with the non-chelated forms and the minuscule amount of the non-chelated form drops so quickly out of solution that the entire chelate population can be depleted quite quickly. (2)

Chelates that respond well to high pH values, like EDDHA, are often much more expensive. In the case of EDDHA, the presence of a lot of isomers of the EDDHA molecule that are weaker chelates, also creates problems with quality control and with the overall strength of each particular EDDHA source. The EDDHA is only as good as its purification process, which makes good sources even more expensive (3, 4).

An additional concern is the oxidation state of the Fe. While Fe chelates are usually prepared using ferrous iron (Fe^{2+}), these iron chelates are quickly oxidized in solution to their ferric iron (Fe^{3+}) counterparts, especially when the solution is aerated to maintain high levels of oxygen. Since Fe^{3+} is both more tightly bound to chelates and more reactive when free – so more toxic when taken up without reduction – plants can have an even harder time mining Fe^{3+} out of chelates (5, 7).

Then there are naturally occurring chelates

There are many organic molecules that can form bonds with the coordination sites of Fe ions. Some of the reviews cited before go into some depth on the different groups of organic molecules that are excreted by both plants and microorganisms as a repose to Fe deficiency that can lead to improved Fe transport into plants. Some of these compounds are also reductive in nature, such that they can not only transport the Fe, but reduce it to its ferrous form such that it can be handled more easily by plants.

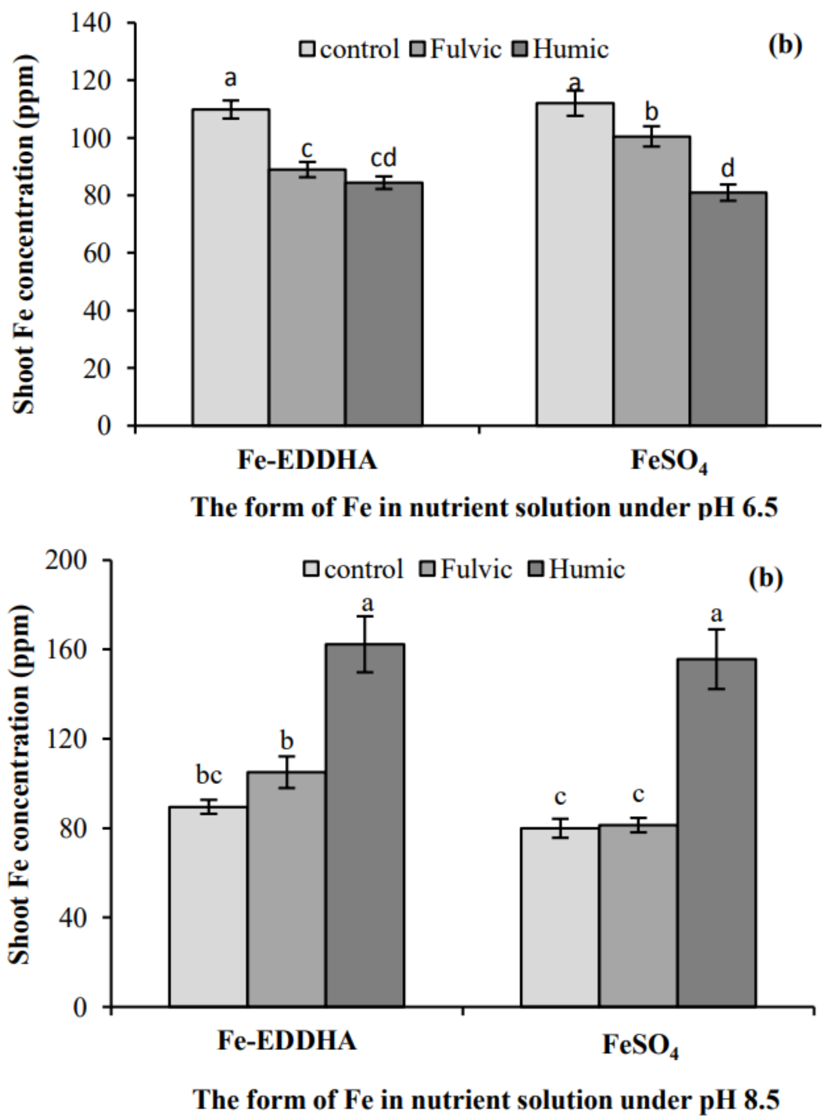
Among the organic compounds that can be used for Fe chelation, humic and fulvic acids have attracted attention, as they can be obtained at significantly low costs and are approved for organic usage under several regulations. You can read more about these substances in some of my previous posts about them

(8, 9). In particular, humic acids are more abundant and are formed by larger and more complex molecules compared to fulvic acids.

The ability of these substances to chelate Fe is much weaker than that of synthetic chelates. The pKb shows us the strength of the binding equilibrium of the chelate with the free metal ion (you can see the values for many metals and chelating agents here). The value for EDTA is 21.5 while that of most humic and fulvic acids is in the 4-6 range (10). This is a logarithmic scale, so the difference in binding strength is enormous. *To put things into perspective, this difference in binding strength is of the same magnitude as the difference between the mass of a grain of sand and a cruise ship.*

Comparing synthetic and fulvic/humic acid chelates

There aren’t many studies comparing synthetic and humic/fulvic acid chelates. One of the most explicit ones (11) compares solutions of Fe sulfate (which we can consider unchelated) and Fe(EDDHA) after additions of fulvic or humic acids in the growth of Pistachio plants. At pH values close to those generally used in hydroponics (6.5) there is hardly any difference between any of the treatments while at higher pH values we have substantially better uptake of Fe in both the EDDHA and unchelated iron treatments when supplemented with either fulvic acid or humic acid.



Images at pH 8.5 of Fe in shoots from the Pistachio study (11)

The idea of using humic acids as a compliment of traditional chelate based fertilization to alleviate high fertilization costs has also been studied in citrus (13). This study confirms some of the findings of the previous one, where additions of humic acids to solutions already containing Fe(EDDHA) provided a more beneficial role than simply the use of the pure humic acid substances or pure Fe(EDDHA) fertilization. Another study on citrus (14) showed that humic acid applications could in fact provide Fe supplementation in calcareous soils (these are soils with high pH values). This shows how humic acid fertilization can rival Fe-EDDHA fertilization.

In another study of leonardite iron humate sources and EDDHA in soybean roots (12) it is apparent that accumulation of Fe in shoots and roots is much worse under the humic acid treatments. In the conclusions of the paper, it is highlighted that the high molecular mass of the leonardite constituents might block the roots of the soybean plants, therefore making it difficult for the plant to transport Fe. However, this study does show that the accumulation of these humic acids in the root zone does promote a decrease in the expression of genes that create Fe transporters and Fe reducing enzymes, pointing that the plant is indeed under less Fe deficiency stress. Another important point is that cycling the humic acid application promotes the absorption of accumulated humic acids, cleaning the roots and allowing for better transport of the Fe in the roots.

In a separate study with humic acid + $FeSO_4$ applications compared to Fe(EDDHA) in sweet cherry ([13]) it was found that the humic acid, when supplemented with unchelated iron, increased Fe tissue as much as the Fe(EDDHA) applications. This was consistent across two separate years, with the second year showing a statistically significant increase of the humic acid treatment over the Fe(EDDHA).

How does this work

An interesting point – as I mentioned before – is that humic/fulvic acids are *incredibly weak* chelating agents. This means that they should release their Fe to the bulk of the solution, which should lead to Fe depletion and deficiencies, as the Fe precipitating mechanisms are thermodynamically much more stable. However this is not what we consistently observe in the studies of Fe nutrition that try to use humic/fulvic acids, either with or without the presence of additional synthetic chelates.

The reason seems to be related with the kinetics of Fe release from these substances. While the stability constants of the chelates are weak – therefore they will release and precipitate in the long term – the bulkiness of the ligands and the complex structures surrounding the metals, makes it hard for the metal to actually escape from the chelate structures around it. However, the fact that the bonding is thermodynamically weak, ensures that the metal can be easily transported once it leaves the organic chelate structure.

Another point is that humic/fulvic substances are reductive in nature, which means that they will protect Fe^{2+} from oxidation by either microbes or oxygen dissolved in solution. They are also sometimes able to reduce Fe^{3+} present in solution back to Fe^{2+}, which can help with the uptake of this Fe by the plant’s root system.

The nature of the above structures and their reductive power depends fundamentally on the actual humic/fulvic acid used, so – as with all cases pertaining to fulvic/humic substances – the source you use will play a big role in determining the final outcome you get.

What chelates are the best?

Current research shows that Fe(EDDHA) and similar chelates, despite their high stability constants, are not perfect. While they can provide ample iron for dicots and can cure Fe deficiencies in the large majority of cases for these plants, these strong chelates are often very expensive and their use as sole Fe sources might be impractical for many cases in traditional agriculture and hydroponics/soilless growing.

The use of humic/fulvic acids complimented with either unchelated Fe or with some lower proportion of stronger iron chelates, seems to be a better overall choice in terms of both plant uptake and economic expense. As shown by several studies mentioned in this post, the effect of humic/fulvic acids and synthetic chelates might actually be synergistic, with both providing different advantages that can be complimentary in hydroponic solutions. These humic/fulvic acid solutions might also be much more favorable for monocot species, where the use of highly stable Fe(EDDHA) chelating agents does not cure deficiency symptoms.

The take away here is that chemical chelate strength is not the only thing to consider. The kinetics of the chelate dissociations, as well as how the chelates interact with the root system, for example how the plant can actually take the Fe outside of the chelating system, are all very important to establish whether the Fe is effectively absorbed and transported by the plants.

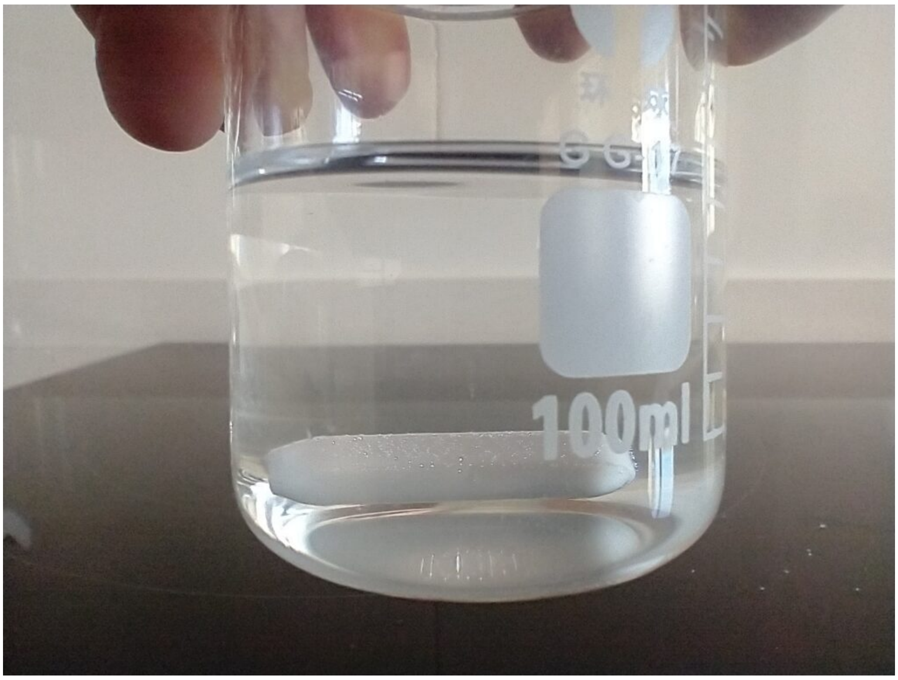
Please note that the topic of Fe nutrition is extremely extensive and while the above is intended to be a short introduction to the topic of humic/fulvic acids and how they compare to synthetic chelates, it is by no means an exhaustive literature review.

Are you using fulvic or humic acids for Fe nutrition? Let us know what your experience is 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.

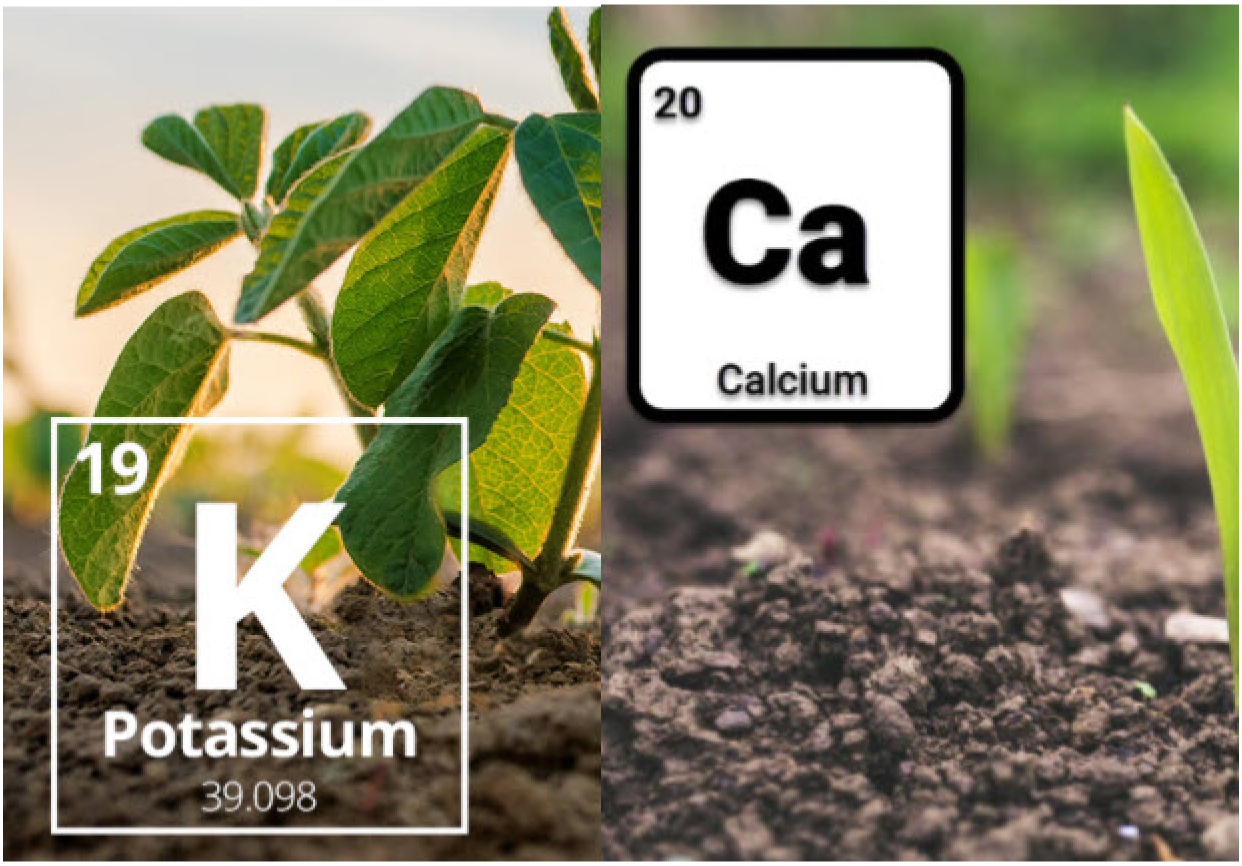
The above process creates a stable mono-silicic acid solution that has an Si concentration of around 1% of Si as SiO_2 and around 0.6% K as K_2O. **Used at 8mL gal it should provide around 20ppm of Si As SiO_2 and 10 ppm of K.**

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!

The Potassium to Calcium ratio in hydroponics

To have a healthy hydroponic crop, you need to supply plants with all the nutrients they need. One of the most important variables that determine proper nutrient absorption, is the ratio of Potassium to Calcium in the nutrient solution. These two elements compete between themselves and have different absorption profiles depending on the environment, and the plant species you are growing. For this reason, it is important to pay close attention to this ratio, and how it changes with time, in your nutrient solution. In this post, we are going to examine peer-reviewed research about this ratio and how changing it affects the growth, quality, and yield of different plant species.



Two vital elements that compete against each other. Their ratio is fundamental to maximize yields and changes depending on the plant species, environmental conditions and absolute concentrations used

Two ions with very different properties

Potassium and Calcium are very different. Potassium ions have only one positive charge and do not form any insoluble salts with any common anions. On the other hand, calcium ions have two positive charges and form insoluble substances with a large array of anions. This creates several differences in the way plants transport and use these two nutrients.

While potassium is transported easily and in high concentrations through the inside of cells, Calcium needs to be transported in the space between cells and its intracellular concentration needs to be very closely regulated. Calcium can also only be transported up the plant –

from roots to shoots – while potassium can be transported up and down as it pleases.

Calcium transport – happening around cells – is heavily dependent on transpiration, which is what causes water to flow through this space. Potassium transport is not so closely related to transpiration, as it can move directly through the inside of cells in large amounts, which means it can be actively transported through the plant in an effective manner.

Note that the above is a broad over-simplification of Potassium and Calcium transport. If you would like to learn more about this topic, I suggest reading these reviews (1,2).

Competition between K and Ca

Potassium and Calcium are both positively charged, so they do compete to a certain extent. The competition is both because they compete for anions – which they need to be paired with for transport – and for the use of electrochemical potential, which they take advantage of to get transported across membranes. However, they do not have the same transport mechanisms, so the competition is limited.

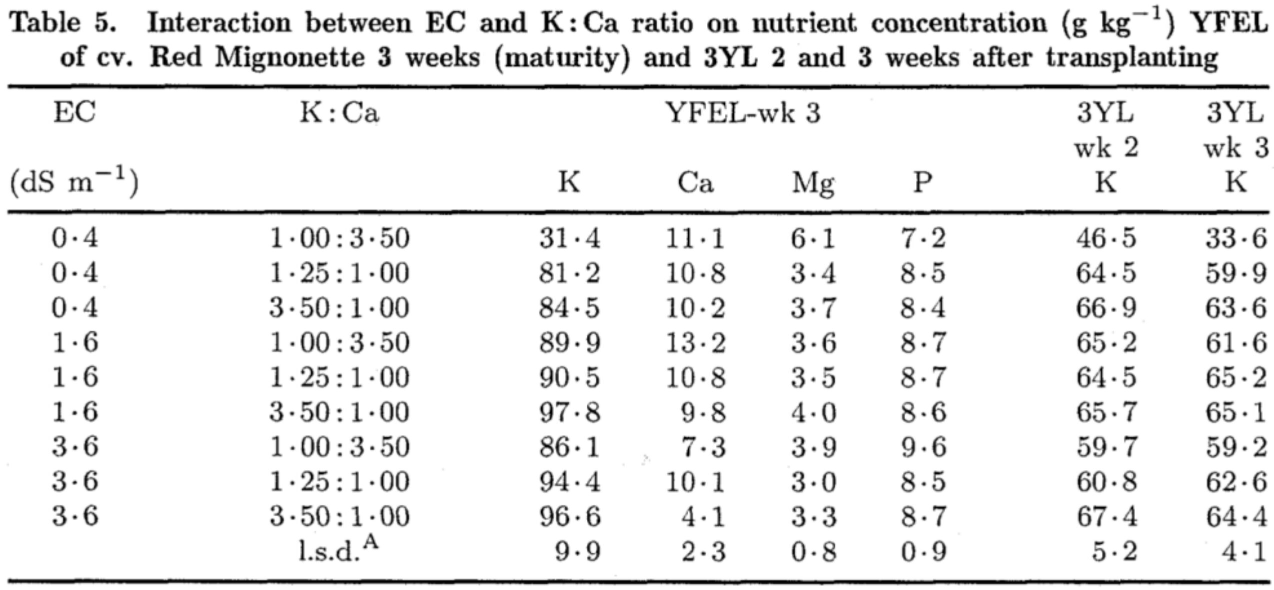


Table 5. **Interaction between EC and K:Ca ratio on nutrient concentration (g kg^{-1}) YFEL of cv. Red Mignonette 3 weeks (maturity) and 3YL 2 and 3 weeks after transplanting**

EC (dS m^{-1})	K:Ca	YFEL-wk 3 K	Ca	Mg	P	3YL wk 2 K	3YL wk 3 K
0·4	1·00:3·50	31·4	11·1	6·1	7·2	46·5	33·6
0·4	1·25:1·00	81·2	10·8	3·4	8·5	64·5	59·9
0·4	3·50:1·00	84·5	10·2	3·7	8·4	66·9	63·6
1·6	1·00:3·50	89·9	13·2	3·6	8·7	65·2	61·6
1·6	1·25:1·00	90·5	10·8	3·5	8·7	64·5	65·2
1·6	3·50:1·00	97·8	9·8	4·0	8·6	65·7	65·1
3·6	1·00:3·50	86·1	7·3	3·9	9·6	59·7	59·2
3·6	1·25:1·00	94·4	10·1	3·0	8·5	60·8	62·6
3·6	3·50:1·00	96·6	4·1	3·3	8·7	67·4	64·4
	l.s.d.^{A}	9·9	2·3	0·8	0·9	5·2	4·1

Table taken from this article (3)

The table above illustrates this point. This study (3) looked into different K:Ca ratios in the growing of lettuce and the effect these ratios had on yield, tip burn, and nutrient concentrations in tissue. You can see that at low total concentrations (0.4 mS/cm EC) the K in tissue is very low when the amount of Ca is high relative to K, while at higher EC values (1.6 mS/cm EC), the K concentration remains basically unaffected, even if the Ca concentration is 3.5 times the K concentration. While Ca competes effectively with K when the absolute concentration of both is low, this competition of Ca becomes quite weak as the concentration of K and Ca increase. At very high concentrations (3.6 mS/cm EC), the potassium does start to heavily outcompete the Ca, especially when the K:Ca ratio is high (3.5x).

The above is also not common to all plants. For some plants, the competition of Ca and K actually reverses compared to the results shown above. However, it is typical for low and high absolute concentration behaviors to be different, and for the influence of K or Ca to become much lower in one of the two cases.

Optimal K:Ca ratios

The K:Ca ratio has been studied for many of the most popularly grown plants in hydroponics. The table below shows you some of these results. It is worth noting, that the results that maximized yields, often did so at a significant compromise. For example, the highest yield for lettuce came at the cost of a significantly higher incidence of inner leaf tip burn. In a similar vein, the highest yields in tomatoes, at a 3:1 ratio, came at the cost of additional blossom end rot problems. This is to say that, although these ratios maximized yields, they often did so with consequences that wouldn’t be acceptable in a commercial setup. For lettuce, 1.25:1 proved to be much more commercially viable, while still giving high yields.

Ref	Plant Specie	Optimal K:Ca
4	Rose	1.5:1
5	Tomato	3:1
6	Tomato	1.7:1
7	Marjoram	0.5:1
8	Strawberry	1.4:1
9	Cucumber	1:1
10	Lettuce	3.5:1

Optimal K:Ca – in terms of yields per plant – found for different plant species

You can see in the above results, that fairly high K:Ca ratios are typically required to increase yields. For most of the commercially grown flowering plants studied, it seems that a ratio of 1.5-2.0:1 will maximize yields without generating substantial problems in terms of Ca uptake. As mentioned above, higher K:Ca often push yields further, but with the presence of some Ca transport issues. A notable exception might be cucumber, for which the publication I cited achieved the maximum yield at a ratio of 1:1. However, good results were still achieved for 1.5:1.

Another important point about the ratio is that it is not independent of absolute concentration. As we saw in the previous section, the nature of the competition between K and Ca can change substantially depending on the absolute ion concentrations, so the above ratios must be taken within the context of their absolute concentration. The above ratios are generally given for relatively high EC solutions (1.5-3mS/cm).

Conclusion

The K:Ca ratio is a key property of hydroponic nutrient solutions. While the optimal ratio for a given plant species cannot be known *apriori*, it is reasonable to assume that the optimal ratio will be between 1:1 and 1:2 for most large fruiting crops and flowering plants that are popularly grown in soilless culture. This is especially the case if the hydroponic solution does not have a low EC. An optimal value below 1:1 is unlikely for most plants, although exceptions do exist in certain plant families that have peculiar Ca metabolisms.

To obtain the largest benefit, it would be advisable to run trials to optimize the K:Ca ratio for your particular crop, by changing the K:Ca ratio between 1:1, 1.5:1, and 2:1. You will likely see important differences when you carry out these trials, which will be useful to determine the highest yielding configuration for your setup. To perform these variations, it is usually easiest to change the ratio of potassium to calcium nitrate used in the nutrient solution.

Have you tried different K:Ca ratios? What do you grow and what has worked for you? Share with us in the comments below!

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. Penningsfeld 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.

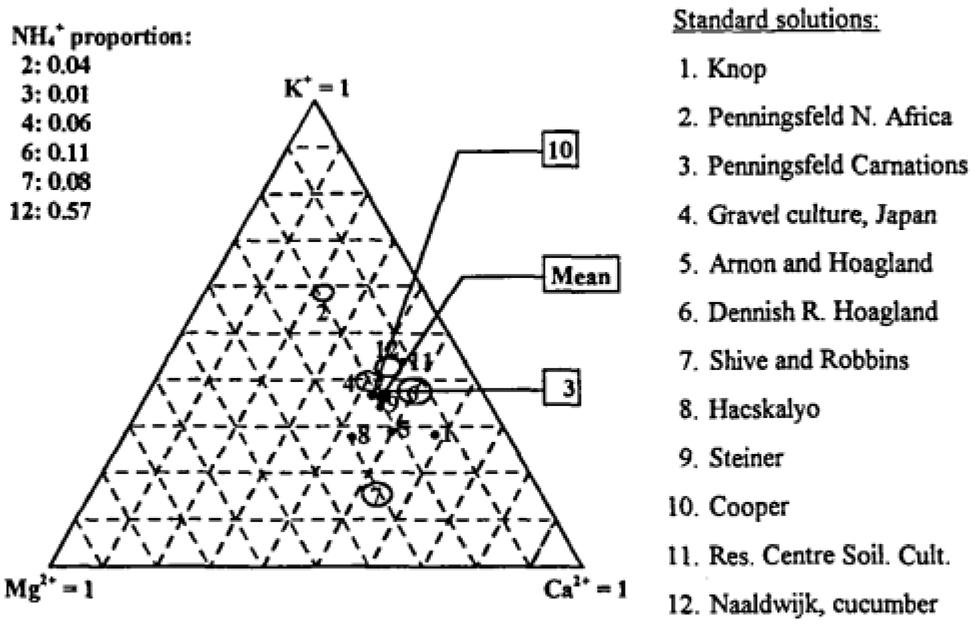


FIGURE 1. Cation composition of the standard solutions.

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

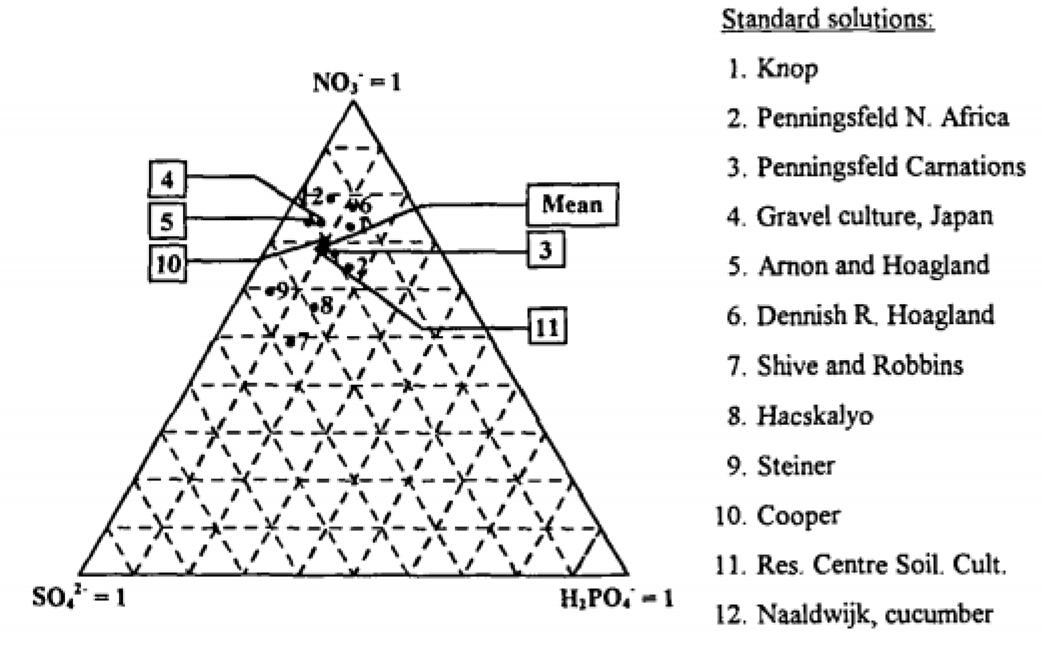


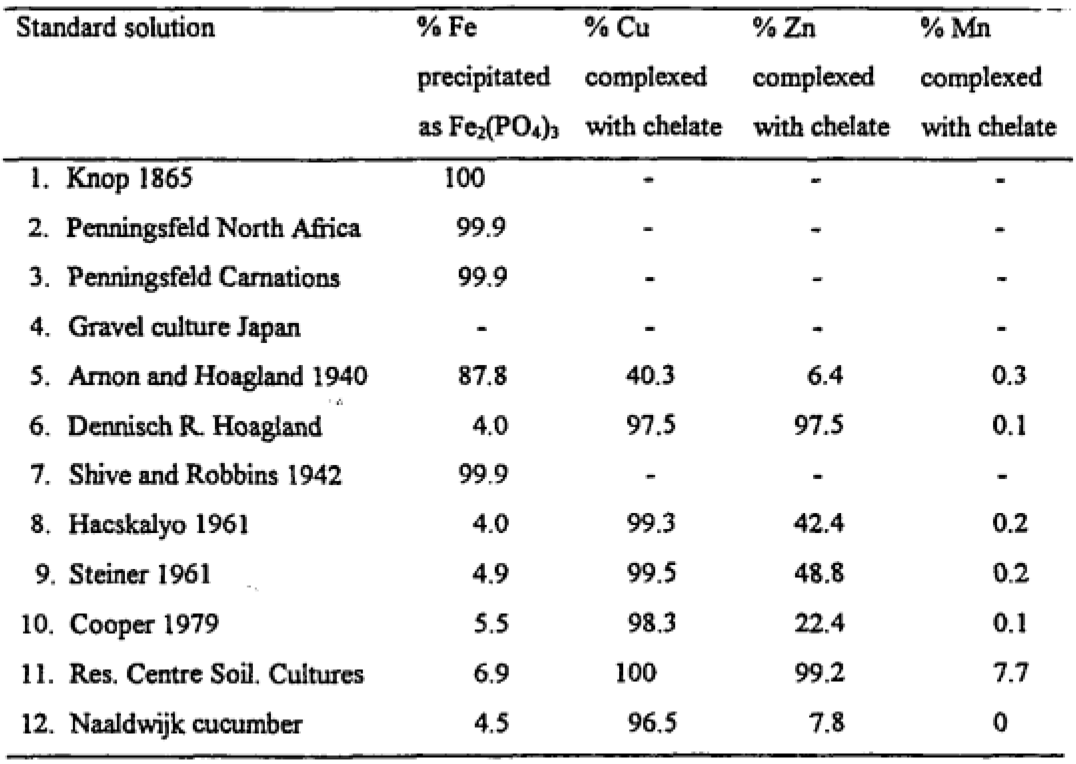
FIGURE 2. Anion composition of the standard solutions.

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

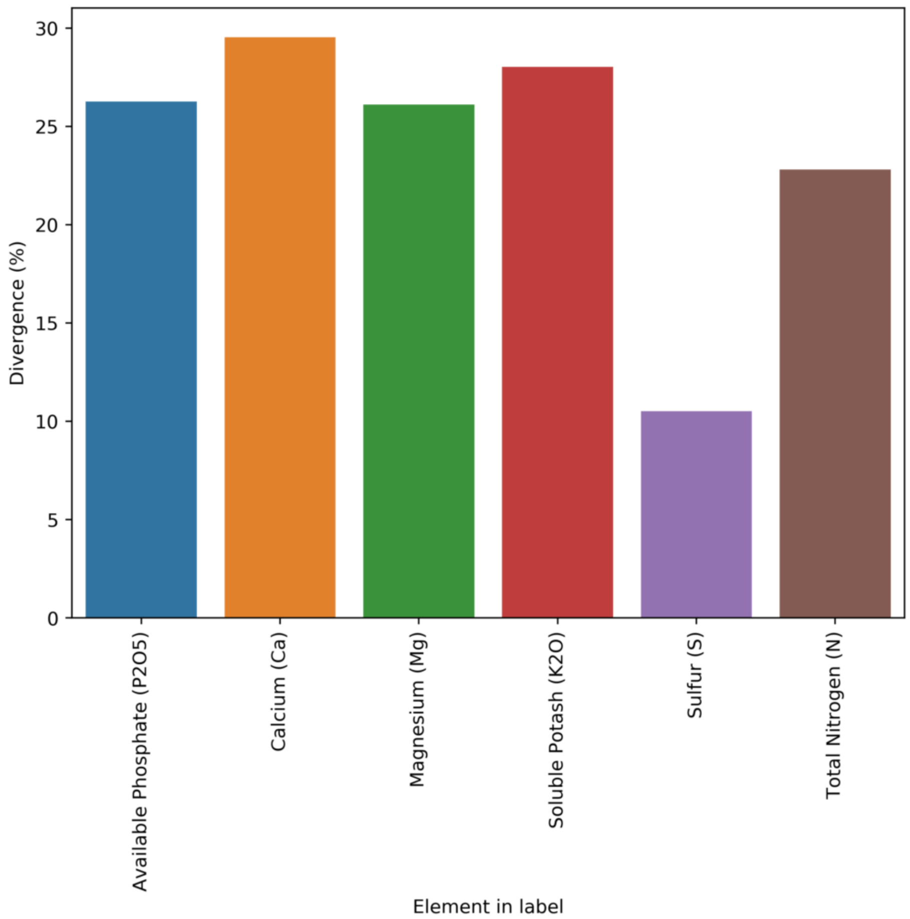
This table shows the precipitated Fe and chelated portions of the micro nutrients in all the standard solutions.

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.

Differences between labels and actual composition values in commercial hydroponic fertilizers

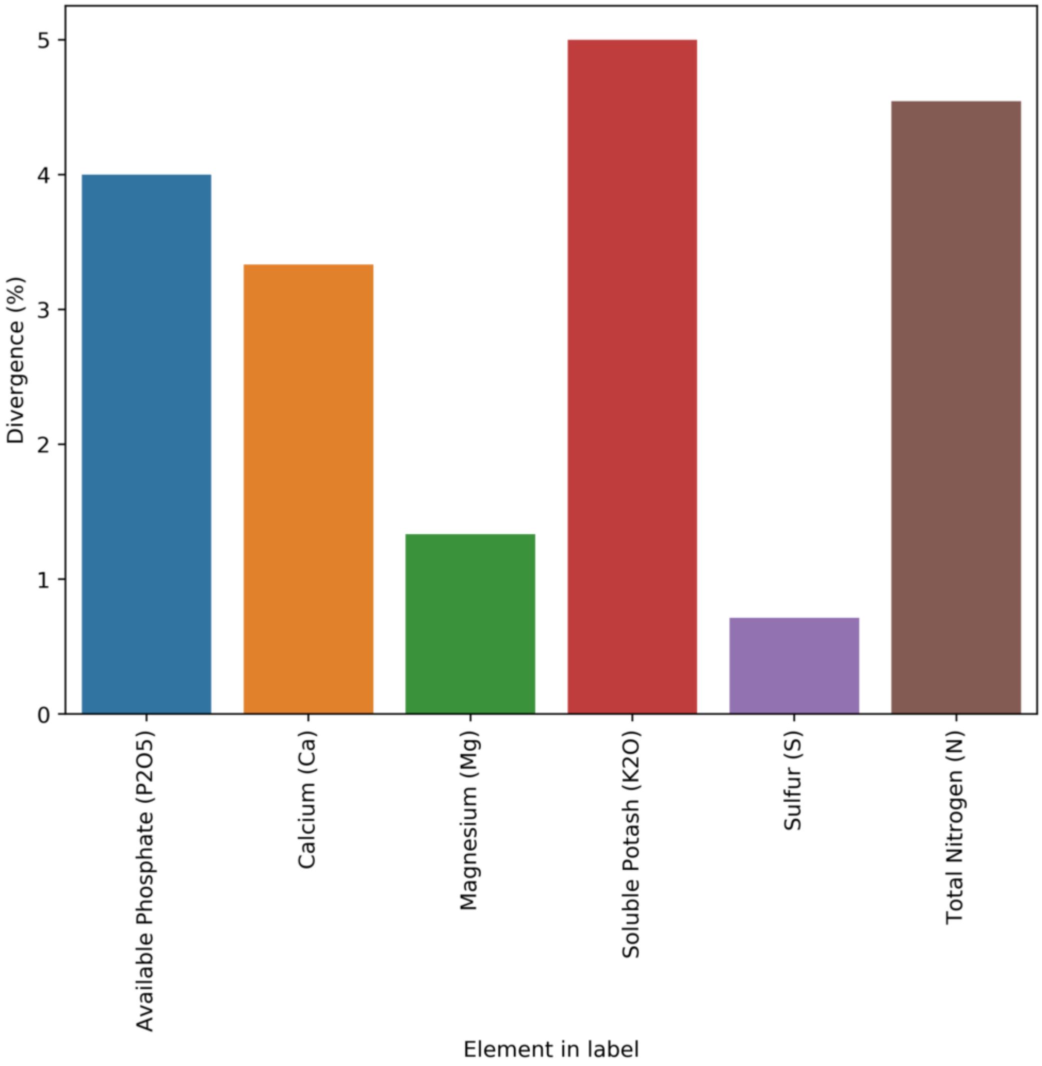
Whenever I am hired to duplicate a company’s fertilizer regime based on commercial products, I always emphasize that I cannot use the labels of the products as a reference because of how misleading these labels can be. A fertilizer company only needs to tell you the minimum amount of each element it 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.



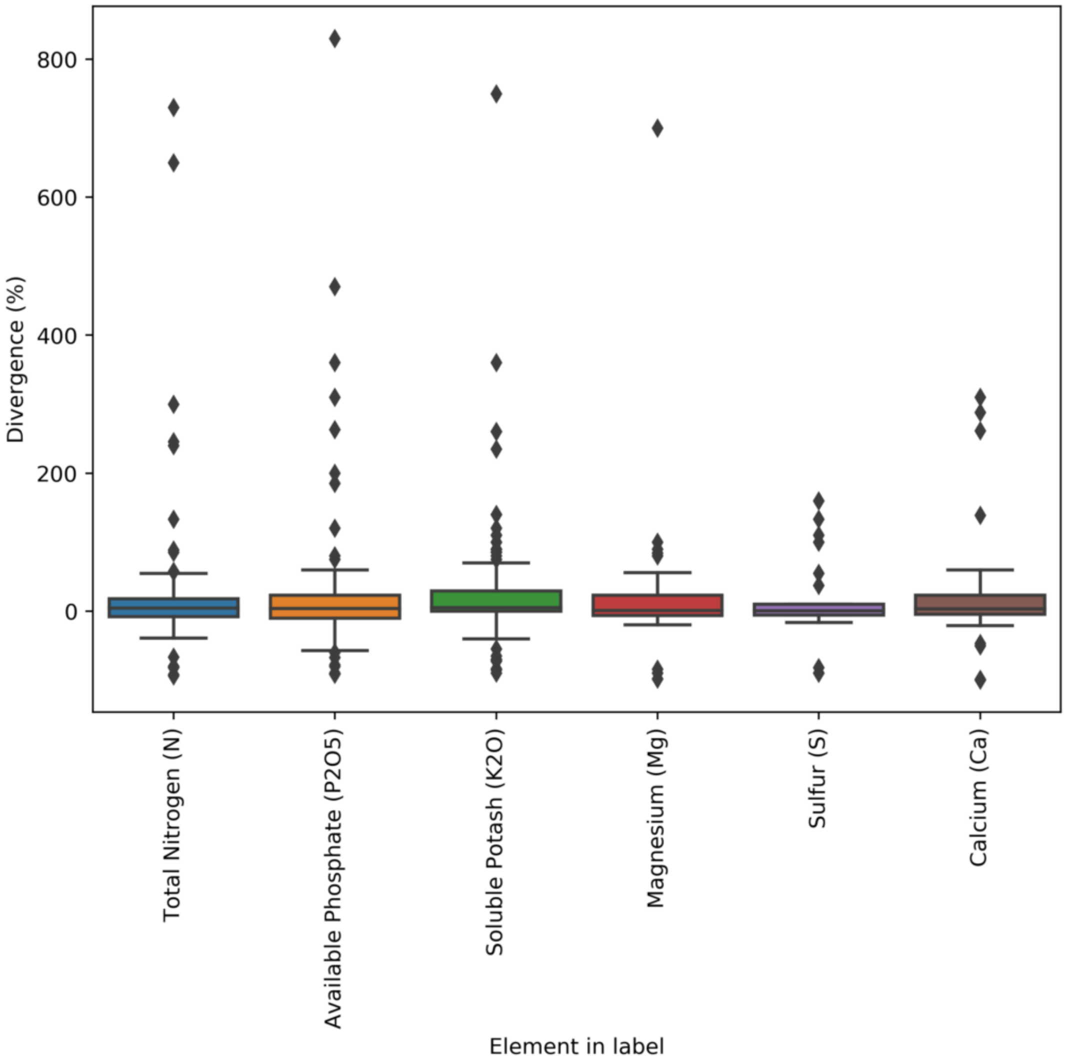
Average deviation from the reported composition on the label compared with lab analysis.

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.

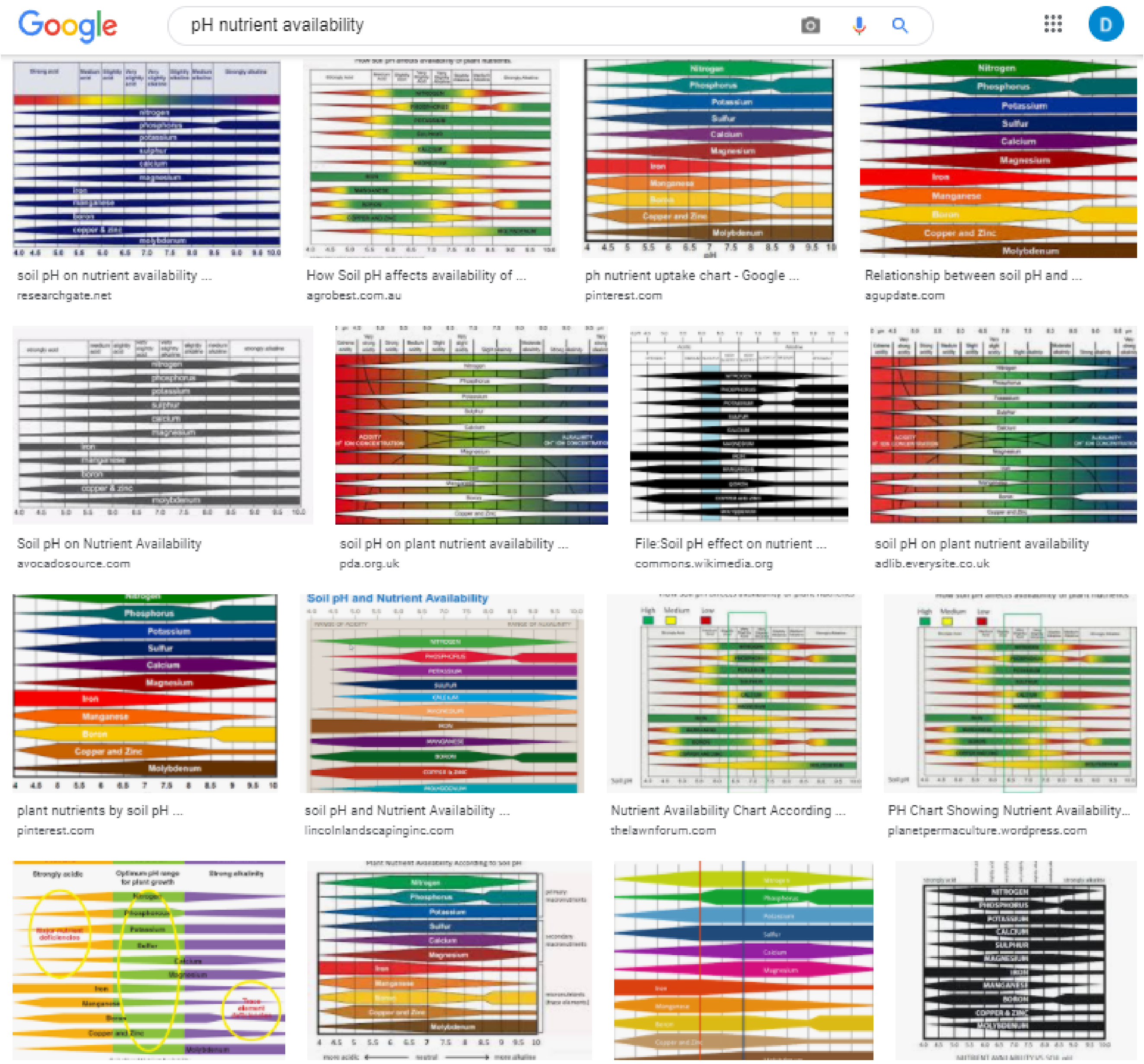
With this information, we can say that most people try to report things within what would be considered reasonable if the label is to remain accurate (deviations in the 1-5% range) to account for their manufacturing issues but many companies will choose to drift heavily for this and report values that 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.

Nutrient availability and pH: Are those charts really accurate?

When growing plants, either in soil or hydroponically, we are interested in giving them the best possible conditions for nutrient absorption. If you have ever searched for information about plant nutrition and pH, you might remember finding a lot of charts showing the nutrient availability as a function of the pH – as shown in the image below – however, you might have also noticed that most of these images do not have an apparent source. Where does this information on pH availability come from? What experimental evidence was used to derive these graphs? Should we trust it? In this post, we are going to look at where these “nutrient availability” charts come from and whether or not we should use them when working in hydroponic crops.



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lincolnlandscapinginc.com

Nutrient Availability Chart According ...
thelawnforum.com

PH Chart Showing Nutrient Availability...
planetpermaculture.wordpress.com

A google search in 2021 showing all the different versions of the same nutrient availability plots.

Information about the above charts is not easy to come by. People have incessantly copied these charts in media, in peer reviewed papers, in journals, in websites, etc. Those who cite, usually cite each other, creating circular references that made the finding of the original source quite difficult. However, after some arduous searching, I was able to finally find the first publication with a chart of this type. It is this white paper from 1942 by Emil Truog of the University of Wisconsin. The paper is titled “The Liming of Soils” and describes Truog’s review of the “state of the art” in regards to the liming of soils in the United States and the differences in nutrient availability that different pH levels

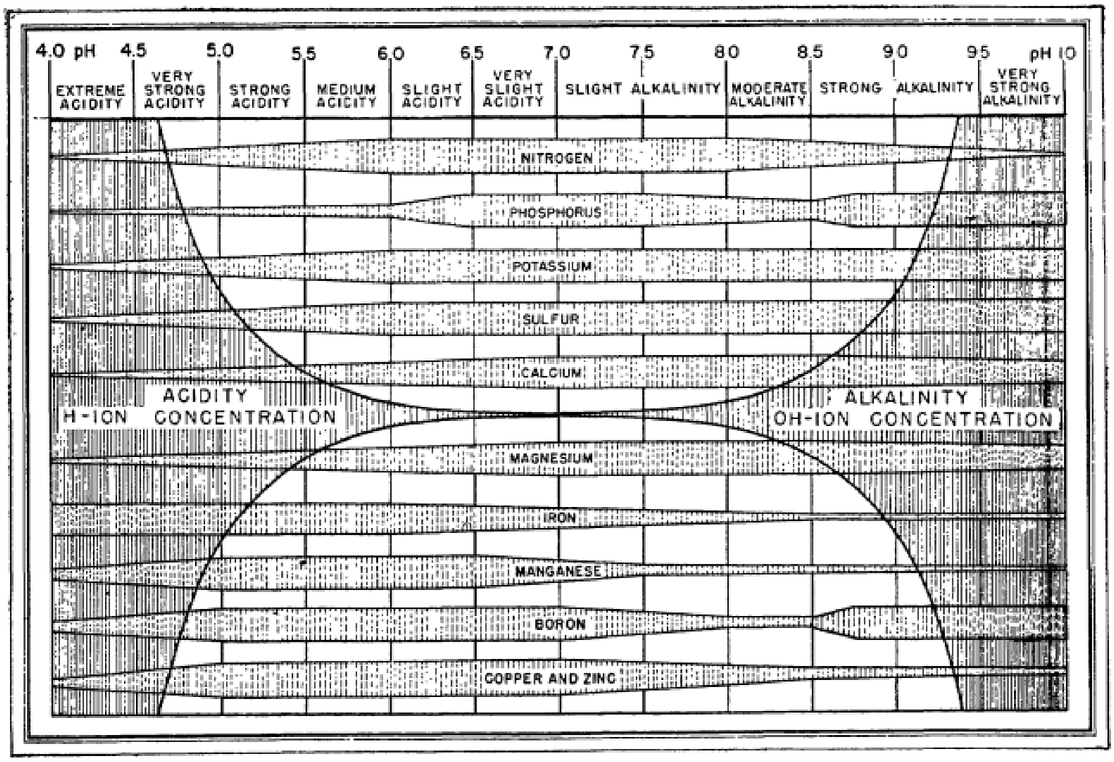
– as set by lime – can cause.

The paper is not based primordially on judicious experiments surrounding nutrient availability but on Truog’s experience with limed soils and the chemistry that was known at the time. He acknowledges these limitations explicitly in the paper as follows:

> *I also emphasize that the chart is a generalized diagram. Because adequate and precise data relating to certain aspects of the subject are still lacking, I had to make some assumptions in its preparation and so there are undoubtedly some inaccuracies in it. There will be cases that do not conform to the diagram because of the inaccuracies, or special and peculiar conditions that are involved, e. g., conditions that are associated with orchard crops.*
>
> *“The liming of soils” by Emil Truog*

It is therefore quite surprising that we continue to use this diagram, even though there have been more than 80 years of research on the subject and we now know significantly more about the chemistry of the matter. Furthermore, this diagram has been extended to use in hydroponics, where it has some very important inaccuracies. For example, Truog’s decision to lower nitrogen availability as a function of pH below 6 is not based on an inability of plants to absorb nitrogen when the pH drops, but on the observations done in soil that showed that below this value, the bacteria present in soil could not effectively convert organic nitrogen into nitric nitrogen, the main source of nitrogen that crops can assimilate. In hydroponics, where nitrate is provided in its pure form, nitrate availability does not drop as the pH of the solution goes down.

Several other such assumptions are present in his diagram. Since the changes in pH he observed are associated with lime content, the drops in availability are as much a consequence of pH increase as they are of increases in the concentration of both calcium and carbonates in the media. This significantly affects P availability, which drops substantially as the increase in pH, coupled with the increase in Ca concentration, causes significant precipitations of Ca phosphates. His diagram also ignores key developments in the area of heavy metal chelates, where the absorption of heavy metal ions can be unhindered by increases of pH due to the use of strong chelating agents.



The original pH availability chart as published by Truoug in the 1940s. It has been copied without barely any modification for the past 80 years.

Diagram from the 1935 paper by N.A. Pettinger

Reading further into Truog's paper, I found out that his diagram is actually an extension of a diagram that was created almost 10 years before, in 1935, by N. A. Pettinger, an associate agronomist at the Virginia Agricultural Experiment station. You can read this white paper here. In a similar fashion, Pettinger created a diagram that summed his experiences with different nutrients in soils at different pH values, where the pH was mainly increased or decreased by the presence or absence of lime. You can see big differences between both diagrams, while Truog includes all elements required by plants, Pettinger only includes the most highly used nutrients, leaving Zn, B, Mo, and Cu out of the picture. Pettinger also has substantially different availability profiles for Mg and Fe.

Although these diagrams are both great contributions to the field of agronomy and have been used extensively for the past 80 years, I believe it is time that we incorporate within these diagrams a lot of the knowledge that we have gained since the 1950s. I believe we can create a chart that is specific to nutrient availability in hydroponics, perhaps even charts that show availability profiles as a function of different media. We have a lot of experimental data on the subject, product of research during almost a century, so I believe I will raise up to the challenge and give it my best shot. Together, we can create a great evidence-based chart that reflects a much more current understanding of nutrient availability as a function of pH.

Understanding Calcium

deficiency issues in plants

Calcium is one of the most difficult elements to properly supply to plants as its absorption is tightly linked to both chemical and environmental factors. It is very easy for growers to suffer from calcium-related problems, especially those who are growing under highly productive conditions. Issues such as bitter pit in apples, black heart in celery, blossom end rot in tomato, and inner leaf tip burn in lettuce, have all been associated with low levels of calcium in the affected tissues. In this post, we are going to discuss why this happens, how it is different for different plants, and which strategies we can use to fix the issue and get all the calcium needed into our plants' tissue. Most of the information on this post is based on these two published reviews (1, 2, 3).

Problems with Ca absorption rarely happen because there is not enough Calcium available to a plant's root system. In hydroponic crops, these issues happen when ample Ca is available to plant root systems and can present themselves even when apparently excess Ca is present in the nutrient solution. Concentrations of 120-200 ppm of Ca are typically found in hydroponic solutions and we can still see cases where nutrient Ca-related problems emerge. This is because issues with Ca are mostly linked to the transport of this element from roots to tissues, which is an issue that is rarely caused by the concentration of Ca available to the plants. **Most commonly these problems are caused by a plant that is growing under conditions that are very favorable and Ca transport fails to keep up with other, more mobile elements.** As the plant fails to get enough Ca to a specific growing point, that tissue will face a strong localized Ca deficiency and will die.

Calcium issues in different plants. Taken from this review.

When looking into a Ca problem and how to fix it, we first need to understand which plant organ is lacking proper Calcium uptake. In tomato plants, for example, blossom end rot (BER) appears when Ca fails to reach a sink organ – the fruit – while in lettuce, inner tip burn develops because Ca is unable to reach a fast-growing yet photosynthetically active part of the plant. Since Calcium transport can be increased by increasing transpiration, we might think that decreasing the relative humidity (RH) might reduce BER but this in fact increases it, because transpiration increases faster in leaves, than it does in the fruit. In this case, solving the problem involves balancing Ca transport so that it reaches the fruit instead of the leaves. Pruning of excessive leaf tissue, lowering N to reduce vegetative growth, and increasing RH – especially at night – can in fact help under these circumstances, where Ca deficiency develops in sink organs. Reducing ammonium as much as possible can also help, as ammonium can also antagonize calcium absorption due to its cationic nature.

In plants like cabbages and lettuce, a different picture emerges. In this case, increasing the RH leads to worse tip burn symptoms, and decreasing it significantly reduces tip burn, as Ca transport is increased by the increased leaf transpiration. This can be a viable strategy if the temperature is not too high. Under high temperatures, reducing RH leads to too much water stress, which causes other problems for the plants. In these cases, a preferred technique to reduce tip burn is to increase air circulation, which decreases both the RH around leaf tissue and the temperature of the plant due to the wind-chilling effect, this can increase transpiration rates without overly stressing plants.

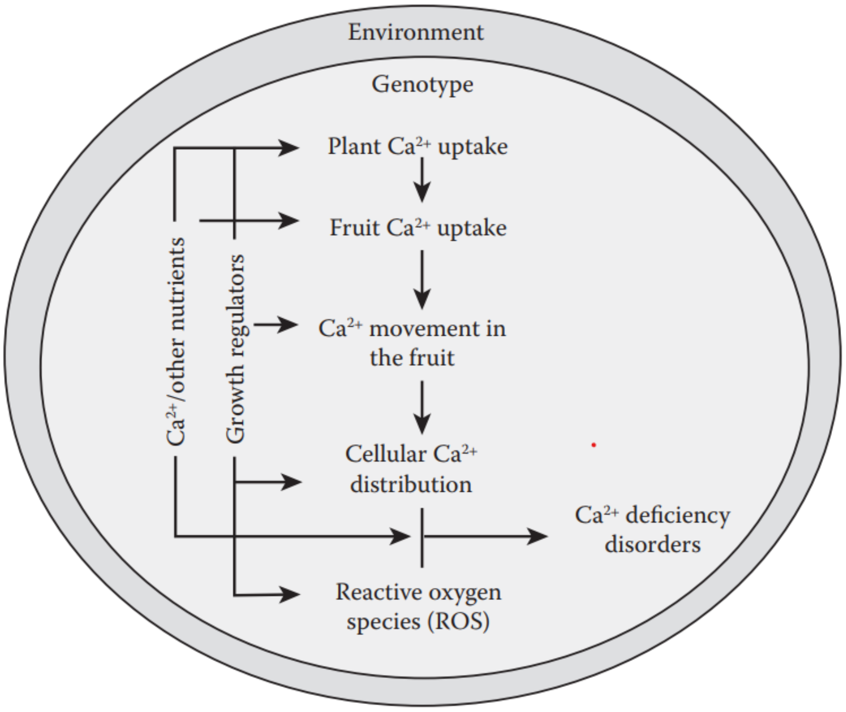


Figure 15.3 Potential mechanisms regulating Ca^{2+} deficiency disorders in fruit and vegetables.

Taken from this review.

Since in most cases these Ca issues are associated with fast growth, most measures that reduce growth will tend to reduce the severity of the Ca symptoms. Reducing the EC of solutions, reducing temperatures, and decreasing light intensity are some of the most popular mechanisms to reduce Ca problems by reducing plant productivity. These might be the most economical solutions – for example, if artificial lights are used – but it might not be favored by many growers due to the fact that it requires a sacrifice in potential yields. A potential way to attack Ca issues through growth control without reducing yields is to use growth regulators in order to suppress vegetative growth. Synthetic and natural gibberellin inhibitors are both effective at this task.

A common strategy to tackle these Ca issues is to perform foliar sprays to correct the deficiency. Weekly, calcium nitrate or calcium chloride foliar sprays can help alleviate symptoms of tip burn and black heart. Spraying plants from a young age, to ensure they always have Ca in their growing tips, is key. When performing these sprays, primordially make sure all growing tips are fully covered, as Ca sprayed on old tissue won’t really help the plant, as Ca cannot be transported from old to young leaves.