Growing Soilless Crops Without Nitrates: Practical Options When Nitrate Salts Are Unavailable

For growers in regions where geopolitical conflicts or economic constraints limit access to nitrate fertilizers like calcium nitrate and potassium nitrate, the question arises: can you grow hydroponic or soilless crops using only alternative nitrogen sources? The short answer is yes, but with important limitations and necessary substrate modifications. This post explores the science behind nitrate-free soilless growing and practical strategies for growers facing nitrate scarcity.

Figure 1. Effects of nitrate concentration (25, 50, 75, 100 and 150% of the recommended dose) and proportion of nitrate/ammonium (0:100, 25:75, 50:50, 75:25 and 100/0) in the nutrient solution for hydroponics, on the development of lettuce Iceberg type.

The above image is sourced from (8).

Why Nitrates Dominate in Hydroponics

In conventional hydroponics, 85-95% of nitrogen is supplied as nitrate (NO_3^-) rather than ammonium (NH_4^+). This preference exists for good reasons. Plants can safely store nitrate in vacuoles without toxicity, while ammonium accumulation in plant tissues causes rapid damage (1). In soil, nitrifying bacteria convert ammonium to nitrate before plant uptake, but most soilless substrates lack these microbial communities. Without this conversion, ammonium concentrations that would be harmless in soil become highly toxic in hydroponics.

Research on tomatoes shows that plants supplied with 112 ppm nitrogen as ammonium developed severe toxicity symptoms and produced only one-third the biomass of nitrate-fed plants (1). Even at 14 ppm nitrogen, ammonium-only nutrition suppressed growth compared to mixed nitrogen sources. For lettuce, similar effects occur, with crown discoloration and biomass reductions appearing at 50 ppm ammonium nitrogen (2).

Maximum Safe Ammonium Levels

The tolerance threshold varies by species and conditions, but general guidelines exist:

Crop Type	Maximum Safe Ammonium (% of total N)	Maximum Concentration (ppm N)
Most crops (standard)	10-15%	15-30 ppm
Sensitive crops (tomato, pepper, lettuce)	5-10%	10-20 ppm
Cold conditions (<15°C)	0-5%	0-10 ppm
High light, fast growth	15-20%	20-40 ppm

These limits exist because ammonium uptake is passive and rapid, plants cannot regulate it effectively, and it disrupts calcium and magnesium uptake while acidifying the root zone (3).

Substrate Amendments: Creating Artificial Soil

The key to using higher ammonium levels or organic nitrogen sources is establishing nitrifying bacteria in the substrate. Recent research demonstrates that soilless substrates can be inoculated with microbial communities that convert organic nitrogen to nitrate (4).

Effective substrates for nitrification include rockwool, vermiculite, polyurethane foam, oyster shell lime, and rice husk charcoal. The process requires:

1. **Inoculum source**: Bark compost or mature vermicompost provides ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB). Add 1g per 100mL substrate initially.
2. **Temperature**: Nitrifying bacteria function optimally at 25-42°C. Below 15°C, nitrification slows dramatically, causing ammonium accumulation (5).
3. **Humidity and aeration**: Substrates need >50% relative humidity and adequate oxygen. Waterlogged conditions inhibit nitrification and promote denitrification.
4. **Establishment period**: Allow 2-3 weeks for bacterial colonization before planting. Daily additions of dilute organic fertilizer (6 mg N per 100mL substrate) accelerate establishment.

Practical Nitrogen Sources

Ammonium Salts

Ammonium sulfate ($(NH_4)_2SO_4$) is the most accessible ammonium source globally. At 21% nitrogen, it provides both N and sulfur. However, use caution:

- Never exceed 20% of total nitrogen as ammonium in solution
- Monitor substrate pH closely, as ammonium uptake releases protons and acidifies the root zone
- Increase ratios only under high light and warm temperatures (>20°C)
- Sensitive crops like lettuce, tomato, and pepper tolerate lower ratios

Ammonium phosphate (MAP or DAP) offers nitrogen plus phosphorus but requires even more careful management due to rapid pH shifts.

Urea

Urea ($CO(NH_2)_2$) at 46% nitrogen is economical and widely available. In water, urease enzymes (either from bacteria or added exogenously) hydrolyze urea to ammonium. However, hydroponic studies on various crops show that urea performs poorly as a sole nitrogen source (6). Plants fed only urea exhibited nitrogen deficiency symptoms at low concentrations and toxicity at high concentrations. The primary issues are:

- Insufficient uptake of intact urea by most crop species
- Variable conversion rates without soil bacteria
- pH instability during hydrolysis

Combined applications of urea with nitrate showed better results than urea alone, but if nitrates are unavailable, urea offers limited benefit beyond what ammonium salts provide (6).

Compost and Organic Extracts

Compost leachates and vermicompost teas contain nitrogen primarily as proteins, amino acids, and ammonium. Direct use in inert hydroponics fails because plants cannot efficiently absorb complex organic nitrogen. However, two approaches work:

Aerobic nitrification method: Add organic nitrogen sources like corn steep liquor (1g/L) or fish emulsion plus bark compost (0.5g/L) as bacterial inoculum. Aerate for 12 days, during which bacteria convert organic N and ammonium to nitrate, reaching 100-130 ppm N as nitrate (7). This creates a low-cost, nitrate-containing solution from readily available materials.

Substrate-based mineralization: Inoculate substrates with compost microbes and apply dilute organic fertilizers daily. The substrate acts as a biofilter, mineralizing organic N to nitrate before plant uptake (4). This method requires 2-3 weeks establishment and careful moisture management.

Expected Yield Impacts

When managed properly with substrate amendments and bacterial communities, yields can approach conventional hydroponic levels. Studies show that tomatoes grown with nitrified organic solutions performed comparably to mineral fertilizer controls when adequate nitrate was generated (7).

However, several factors reduce yields in poorly managed nitrate-free systems:

- **Ammonium toxicity**: High ammonium causes 30-70% yield reductions across most crops (1)

- **Nutrient imbalances**: Ammonium competes with Ca^{2+} and Mg^{2+} uptake, inducing deficiencies
- **pH instability**: Root zone acidification from ammonium uptake reduces nutrient availability
- **Incomplete mineralization**: Organic N sources may not fully convert to plant-available forms

Realistic expectations for growers transitioning to nitrate-free systems:

- First crop cycle: 50-70% of conventional yields while optimizing conditions
- Established systems with functioning bacterial communities: 80-95% of conventional yields
- Cold season growing (<15°C): 40-60% due to impaired nitrification

Nutrient Solution Modifications

Without calcium nitrate, calcium must come from chloride or sulfate sources rather than nitrate. Calcium chloride is highly soluble but adds chloride. Gypsum (calcium sulfate) doesn’t have the solubility needed to make concentrated stock solutions and therefore can only be added to the final solutions or added to the media as an amendment. Calcium chloride can add unwanted high amounts of chlorides as it’s therefore best avoided. If you are doing composting amendments then limestone amendments might be the most desirable way to supply Ca to the crop.

Critical Success Factors

To successfully grow soilless crops without nitrate fertilizers:

1. **Establish nitrifying bacteria**: This is non-negotiable for using organic N or high ammonium levels
2. **Monitor pH constantly**: Ammonium acidifies solutions; maintain pH 5.8-6.5 through buffering or base addition
3. **Provide adequate calcium**: Use calcium chloride or sulfate since calcium nitrate is unavailable
4. **Keep temperatures warm**: >20°C substrate temperature for bacterial activity
5. **Start conservatively**: Begin with 10% ammonium and increase gradually as plants adapt
6. **Choose tolerant species first**: Leafy greens like pak choi are more tolerant than tomatoes or peppers

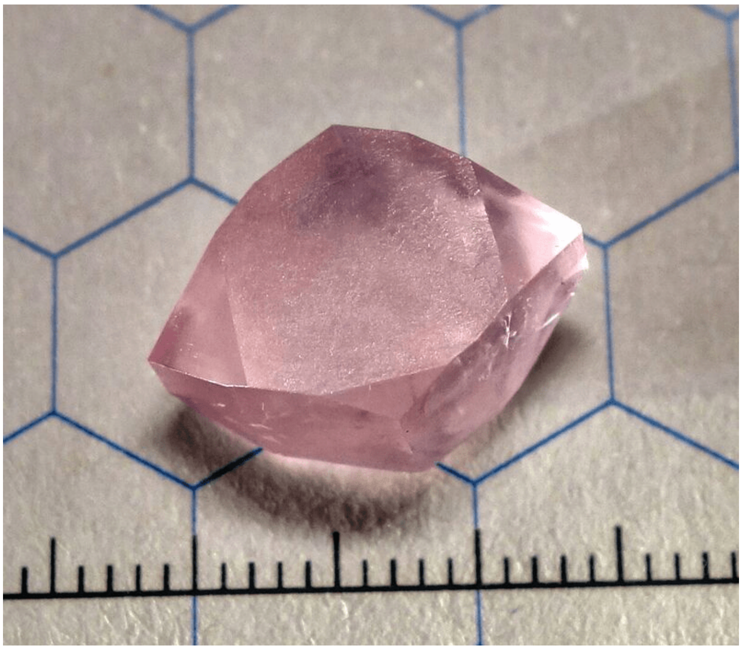
Conclusion

Growing soilless crops without nitrates is achievable but requires different management than conventional hydroponics. The approach depends on creating conditions that mimic soil processes, establishing microbial communities to convert ammonium and organic nitrogen to nitrate within the substrate. While yields may initially be lower, proper substrate inoculation, temperature management, and careful nitrogen source selection can produce acceptable results. For growers with limited access to nitrate salts, combining small amounts of ammonium sulfate (20-30 ppm N) with aerobically nitrified compost teas or inoculated substrates offers the most practical path forward.

Do oil-producing crops need

extra manganese or just enough?

Manganese is a workhorse micronutrient in plants. It is central to photosystem II, essential for the water splitting chemistry, and a cofactor for several enzymes. Given its importance, plants that produce energetically expensive compounds – like oils – might require more of it to run their machinery, so the threshold question is simple: do oilseed or essential oil crops require manganese above what non oil-producers need, or do they just need standard sufficiency with no premium for “oil production status”?



A manganese sulfate crystal. One of the most commonly used salts to supplement Mn in agriculture.

What the literature actually supports

Recent reviews agree on fundamentals. Plant Mn requirements are driven by core physiology like photosynthesis and redox balance, not by whether a crop partitions carbon to oil, starch or protein. There is no general evidence for a higher

Mn setpoint in oil-producing species as a class. Instead, yield and quality respond to correcting deficiency and avoiding toxicity, the same rule that governs non oil-producing crops (1), (2).

Oilseeds

- **Soybean.** Classic work shows severe Mn deficiency reduces seed oil percentage. Once deficiency is corrected, pushing Mn higher does not increase oil; excess Mn depresses growth and yield. In other words, soybean needs adequate Mn, not extra because it is an oilseed (3), (4).
- **Canola/rapeseed.** Liming-induced Mn deficiency is common on high pH soils. Foliar Mn corrects deficiency and restores yield, but applications on adequate plants do not increase oil or seed yield. Again, the benefit is deficiency correction, not a special oil-crop premium (5).

Essential oil crops

- **Water mint (Mentha aquatica).** In solution culture, applying 100 µM Mn sulfate, which is ~5.5 ppm Mn, increased leaf glandular trichome density and essential oil yield relative to a lower Mn background. This shows Mn can modulate secondary metabolism when the baseline is low, but it does not prove that mint requires Mn above typical sufficiency ranges; it shows that deficiency or marginal supply limits oil yield and composition (6).
- **Feverfew (Tanacetum parthenium).** Varying Mg and Mn in controlled media shifted essential oil profiles. Mn interacted with Mg to alter monoterpene vs sesquiterpene proportions, again indicating composition sensitivity

under limited or imbalanced supply rather than a universal need for “extra Mn” (7).

Soilless and hydroponic angle

Hydroponics removes soil redox chemistry, so Mn availability is governed by solution concentration, chelation and pH. Reviews emphasize that plants still follow the same homeostatic rules; oil status does not change the Mn target. In recirculating systems, Mn can drift due to adsorption, precipitation at higher pH and plant uptake, which explains sporadic deficiency in otherwise balanced recipes. Correct the drift and the symptoms resolve; adding more than sufficiency is unnecessary and risks toxicity, especially at low pH (1), (2).

Evidence summary

Crop	**System**	**Mn supplementation rate (ppm Mn)**	**Outcome on oil yield or composition**	**Take-home**	**Study**
Soybean	Sand/solution culture	Not specified here in ppm	Severe Mn deficiency lowered seed oil; correcting deficiency restored yield but extra Mn gave no benefit	Adequacy matters, excess does not help	(3), (4)
Canola	Field, calcareous soils	Foliar Mn, rate study	Yield gains only where tissue was Mn-deficient; no gain in Mn-sufficient stands	Target deficiency, not blanket “oil-crop” boosts	(5)

Crop	System	Mn supplementation rate (ppm Mn)	Outcome on oil yield or composition	Take-home	Study
Water mint	Nutrient solution	~5.5	Increased trichome density and essential oil yield from a low-Mn baseline	Adequate Mn is required for EO biosynthesis; no proof of supra-sufficiency need	(6)
Feverfew	Controlled media	Varied Mn, ppm not reported	Mn with Mg shifted monoterpene vs sesquiterpene proportions	Composition responds to Mn status; optimize for sufficiency	(7)

Tissue composition: are oil plants different?

Authoritative reviews catalog Mn uptake, transport and intracellular allocation across species. None propose distinct Mn sufficiency thresholds based solely on oil production. The drivers are photosynthetic demand, transporter regulation and rhizosphere chemistry. Oilseed and essential oil crops display the same deficiency symptoms and toxicity risks as other species. Practically, tissue targets should be set by species-specific sufficiency ranges and growth stage, not by “oil producer” status (1), (2).

Practical stance for soilless growers

1. **Aim for sufficiency, verify with tissue tests.** If chlorosis and interveinal speckling suggest Mn deficiency and tissue Mn is low, bring solution Mn up to a normal range and adjust pH. Do not chase extra Mn for

oil content once sufficiency is confirmed (5).

2. **Watch pH and redox.** Slight pH rises or oxidizing conditions can drop available Mn even when total Mn dosing looks fine. Correct pH and renew chelates before increasing Mn concentration (1).
3. **Expect composition shifts near the margins.** In mint and feverfew, Mn status influenced essential oil profile when supply was marginal. That is a signal to maintain adequacy, not a license to overapply (6), (7).

Bottom line

There is no broad academic support for supplementing manganese above normal sufficiency just because a crop produces oil. The consistent finding is boring but useful: correct Mn deficiency and keep supply in a normal, pH-stable window. Oilseed yield and essential oil profiles suffer when Mn is low, and they recover when Mn is adequate. Beyond that, extra Mn does not buy more oil and can cost you growth.

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

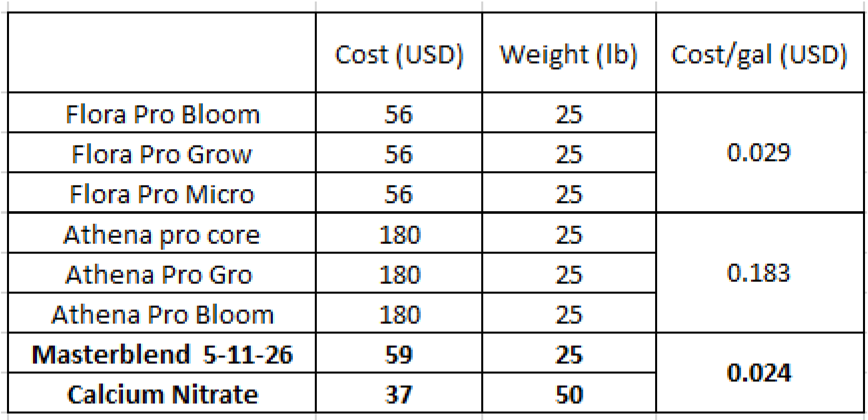
The cost analysis focuses on the US market. The prices I obtained for boutique fertilizers are from google searches where I found the cheapest costs at the highest scale I could find. For commodity fertilizers I used the price points of customhydronutrients.com, which is a trust-worthy website for the 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**	

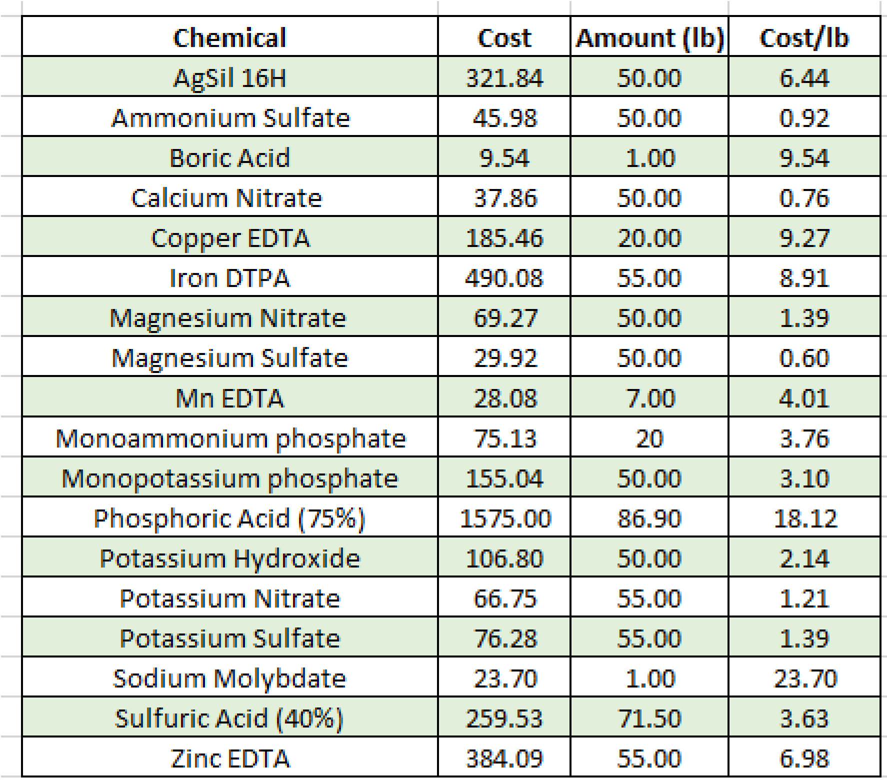
Table comparing a couple of boutique lines with a standard 5-11-26 preparation using a Masterblend product and Calcium nitrate.

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

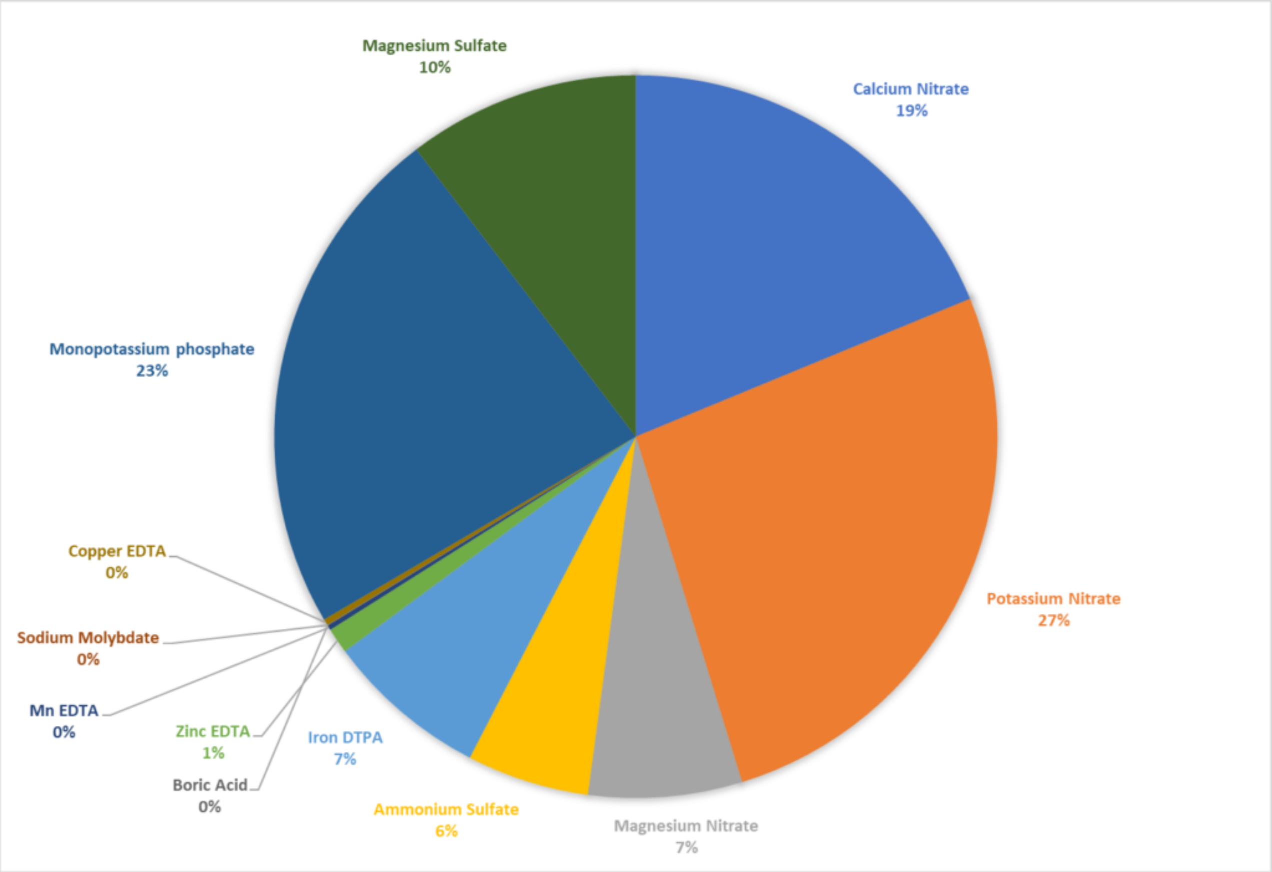
It is also interesting to consider the case of raw fertilizer inputs as this allows us to better think about formulations to reduce cost and also calculate whether making custom fertilizers is worth the expense. The table below shows you some commonly used bulk fertilizer inputs, their cost in USD and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

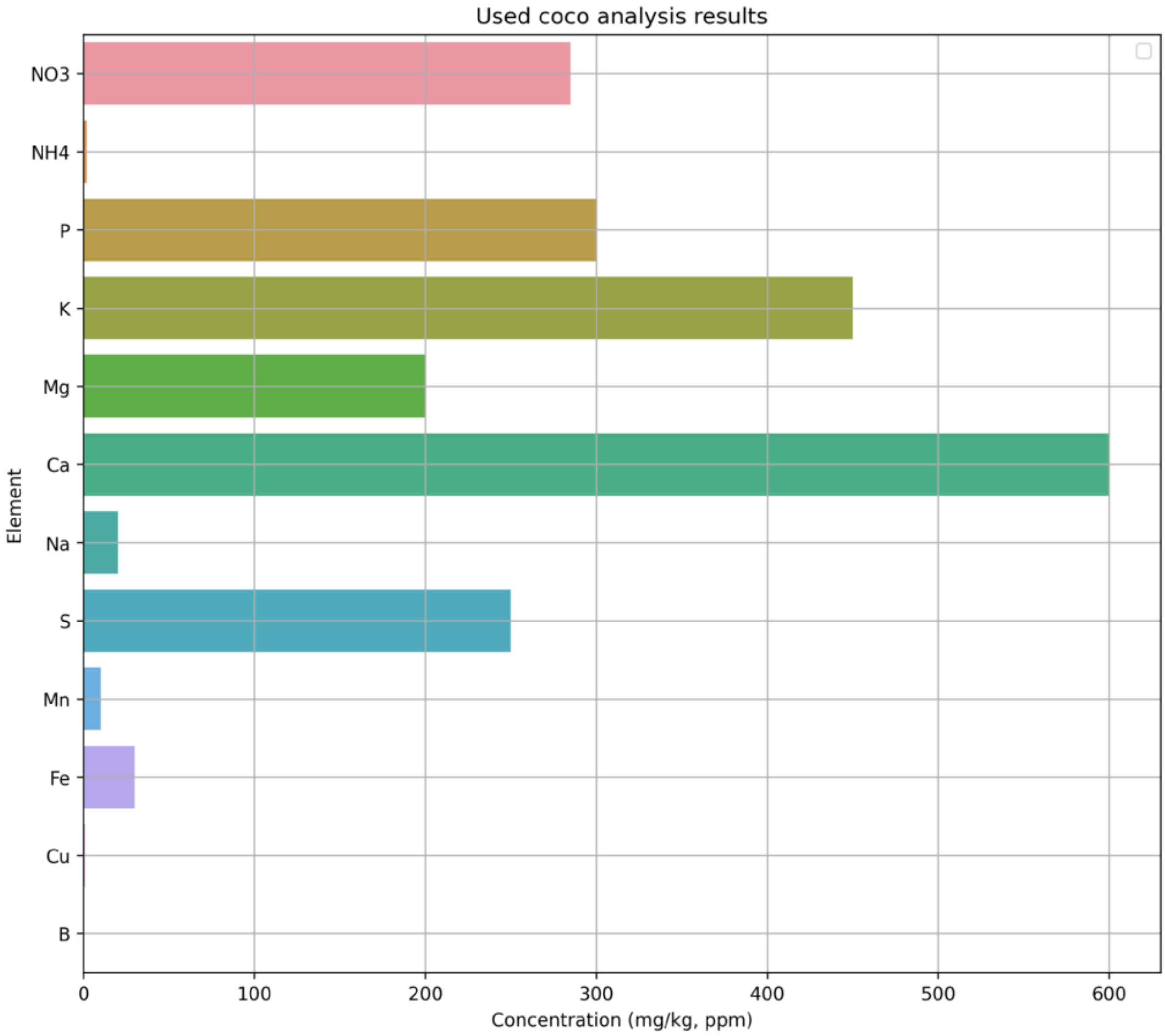
Why media is often not reused

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.

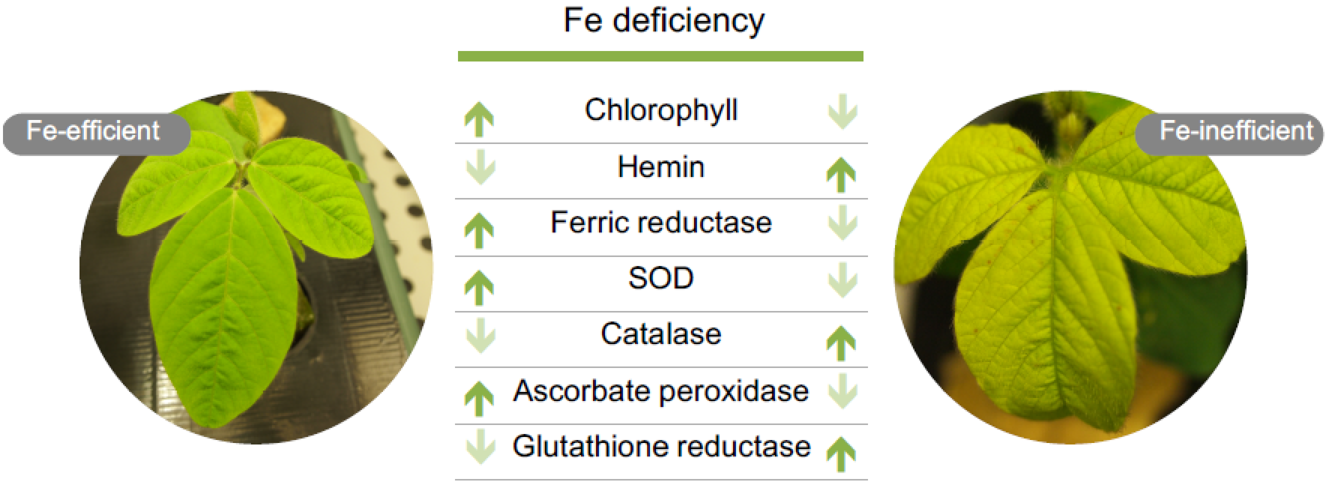
Do you reuse your coco? Let us know which strategy you use and what you think about my strategy!

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.



	Fe deficiency	
↑	Chlorophyll	↓
↓	Hemin	↑
↑	Ferric reductase	↓
↑	SOD	↓
↓	Catalase	↑
↑	Ascorbate peroxidase	↓
↓	Glutathione reductase	↑

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.

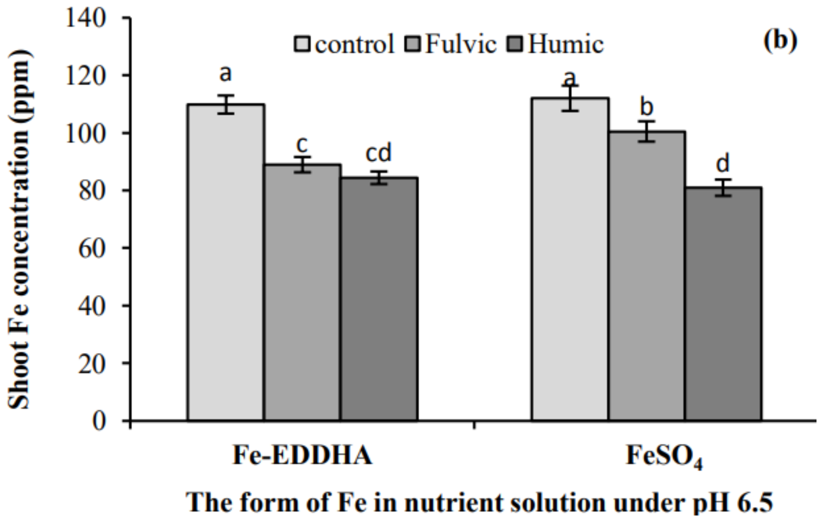
Among the organic compounds that can be used for Fe chelation, humic and fulvic acids have attracted attention, as they can be obtained at significantly low costs and are approved for organic usage under several regulations. You can read more about these substances in some of my previous posts about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

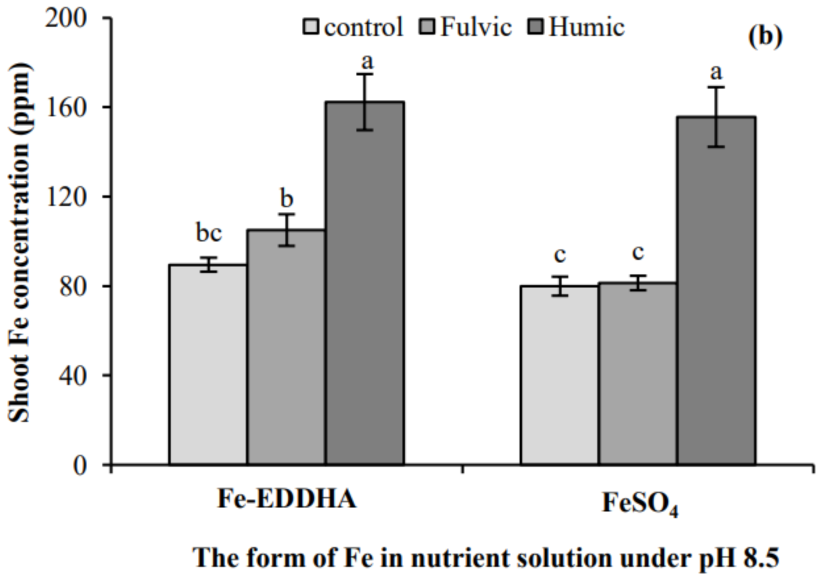
(8, 9). In particular, humic acids are more abundant and are formed by larger and more complex molecules compared to fulvic acids.

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.

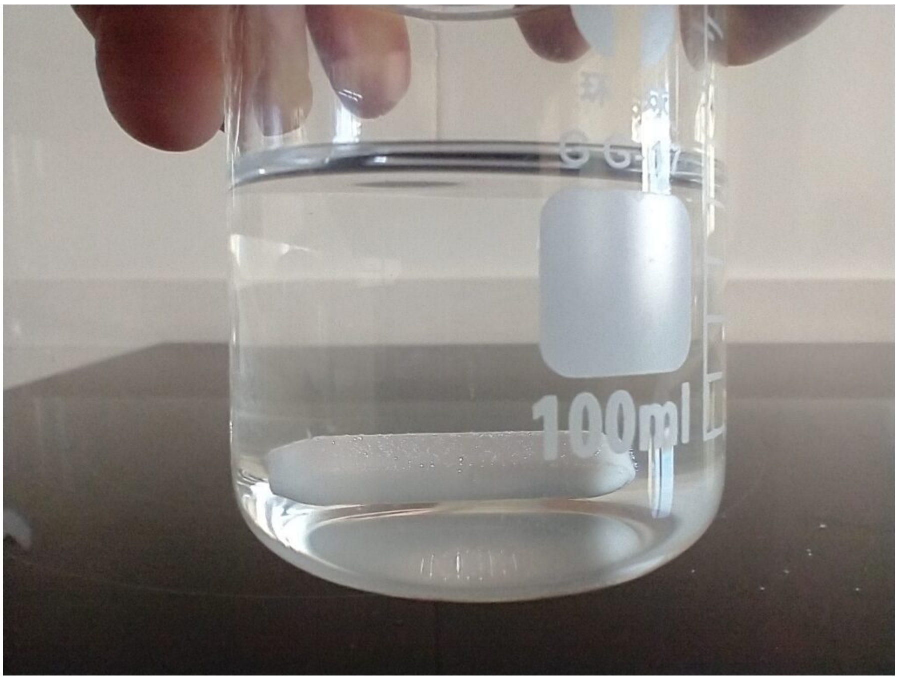
Please note that the topic of Fe nutrition is extremely extensive and while the above is intended to be a short introduction to the topic of humic/fulvic acids and how they compare to synthetic chelates, it is by no means an exhaustive literature review.

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.

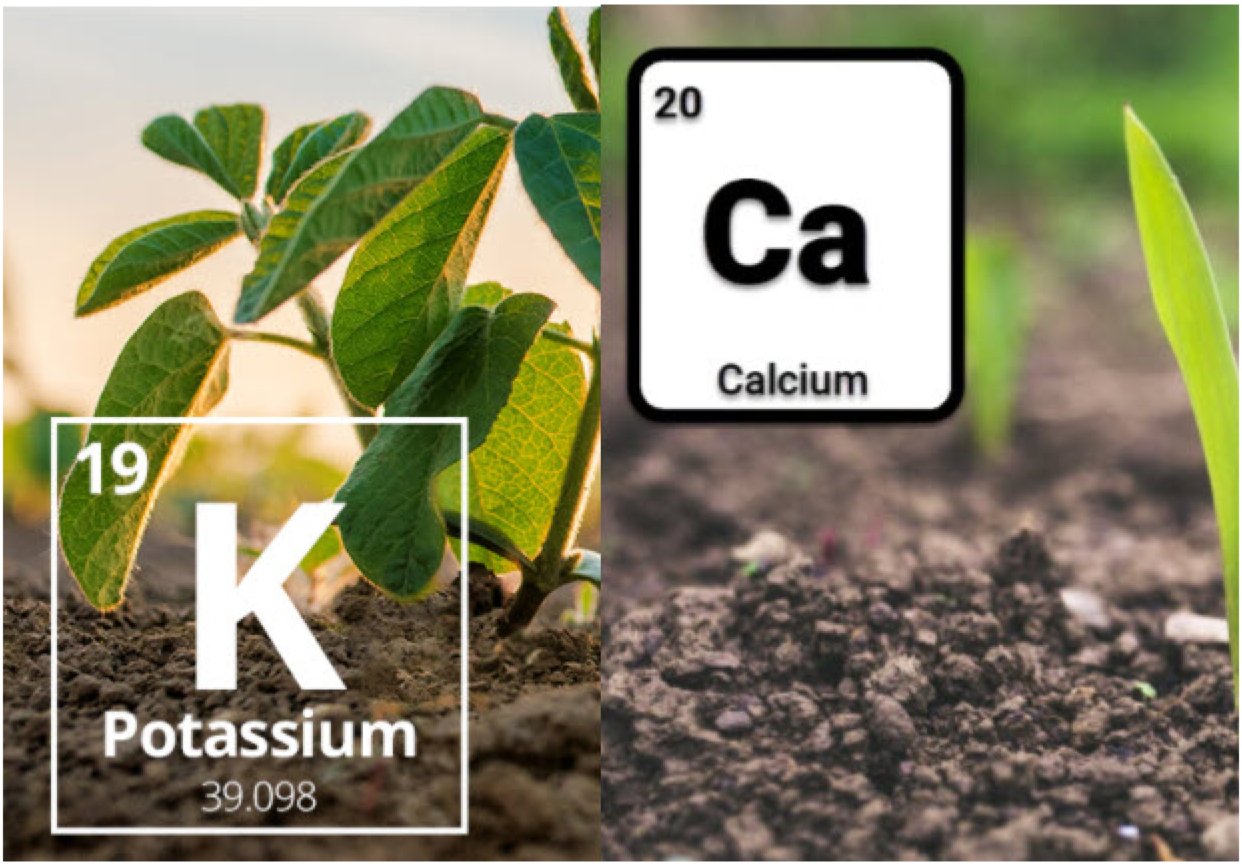
The above process creates a stable mono-silicic acid solution that has an Si concentration of around 1% of Si as SiO_2 and around 0.6% K as K_2O. **Used at 8mL gal it should provide around 20ppm of Si As SiO_2 and 10 ppm of K.**

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.

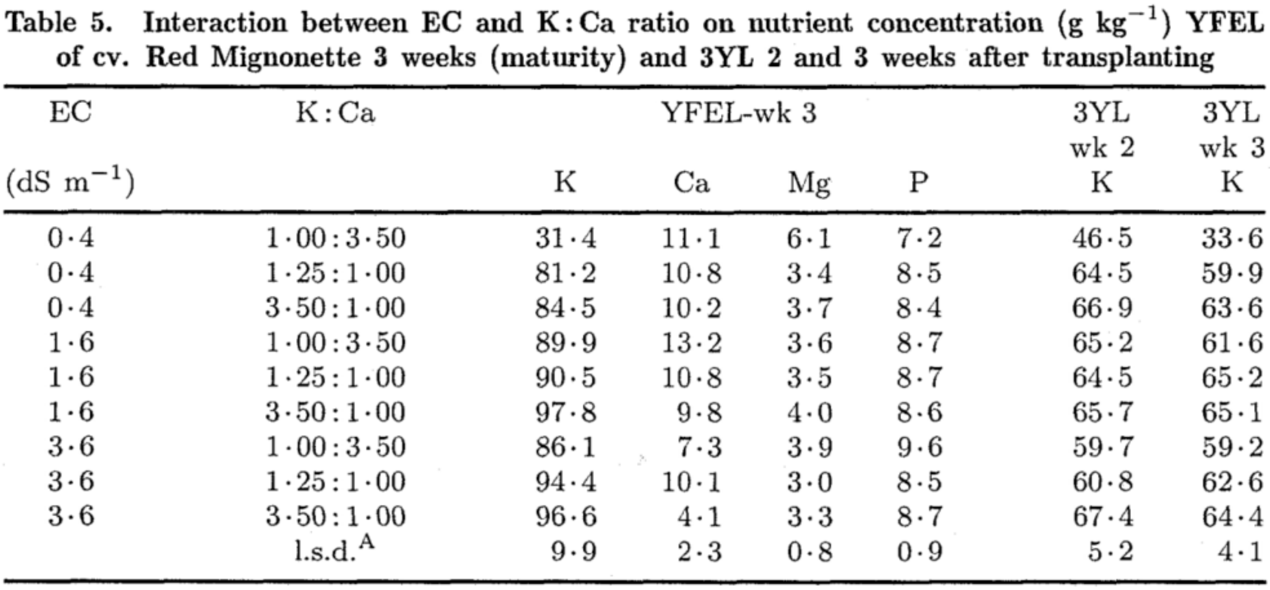


Table 5. Interaction between EC and K : Ca ratio on nutrient concentration (g kg^{-1}) YFEL of cv. Red Mignonette 3 weeks (maturity) and 3YL 2 and 3 weeks after transplanting

EC ($dS\ m^{-1}$)	K : Ca	YFEL-wk 3 K	YFEL-wk 3 Ca	YFEL-wk 3 Mg	YFEL-wk 3 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.

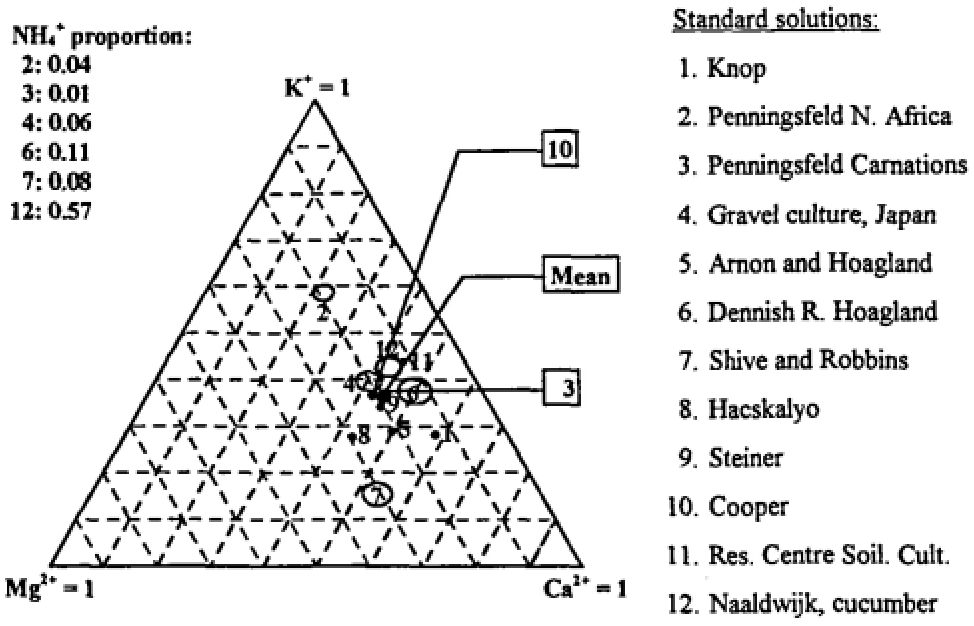


FIGURE 1. Cation composition of the standard solutions.

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

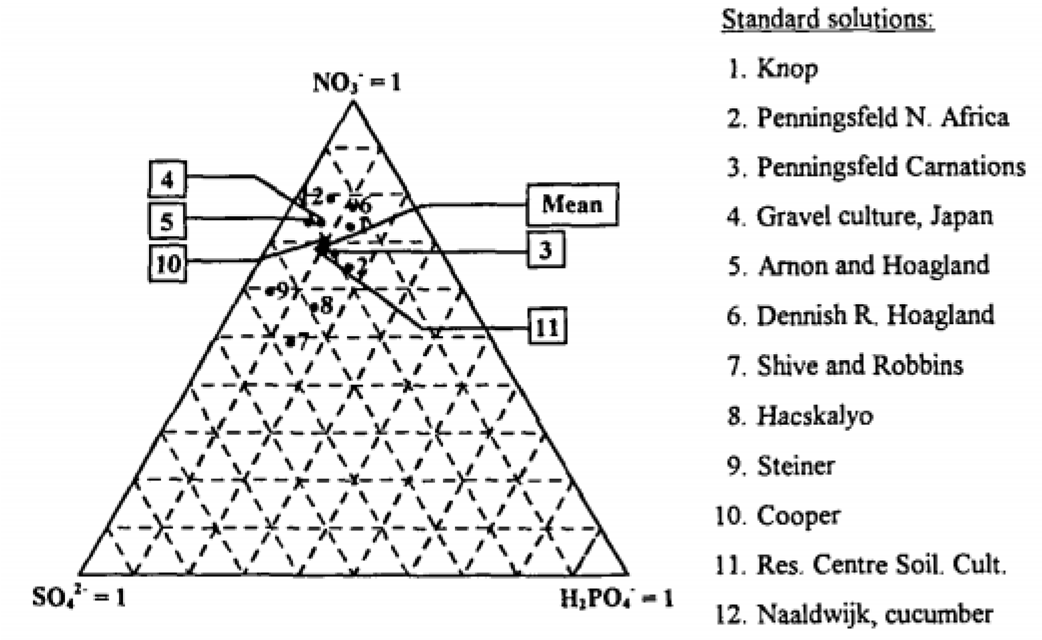


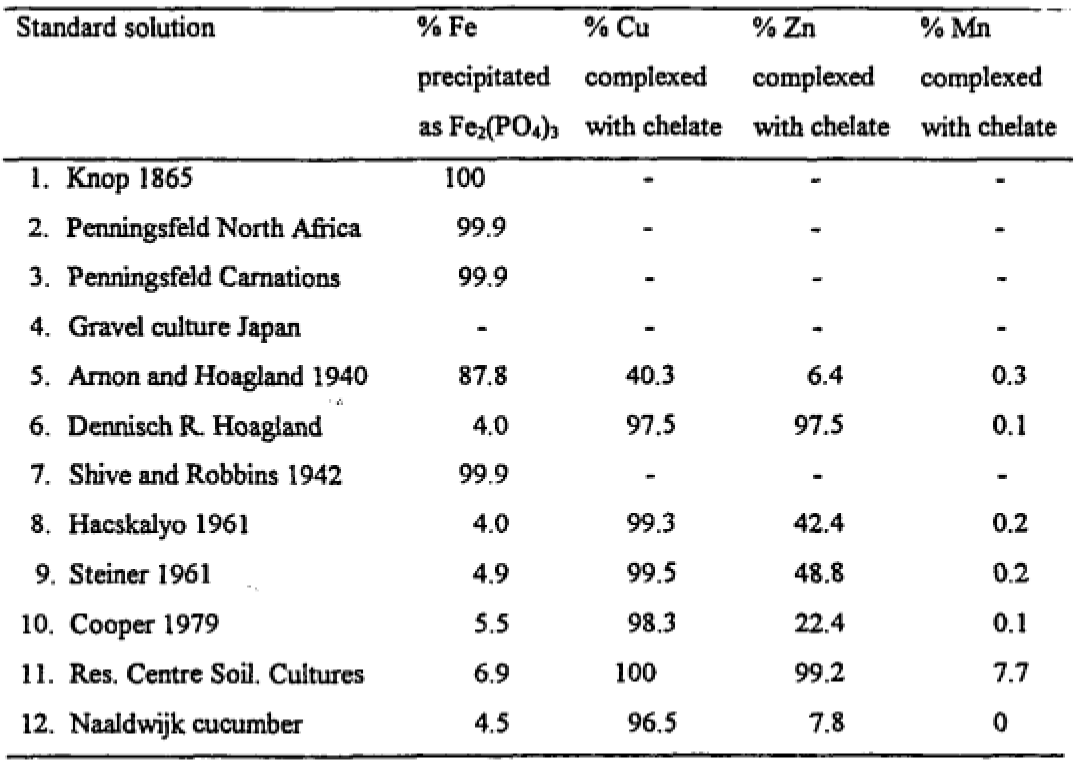
FIGURE 2. Anion composition of the standard solutions.

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

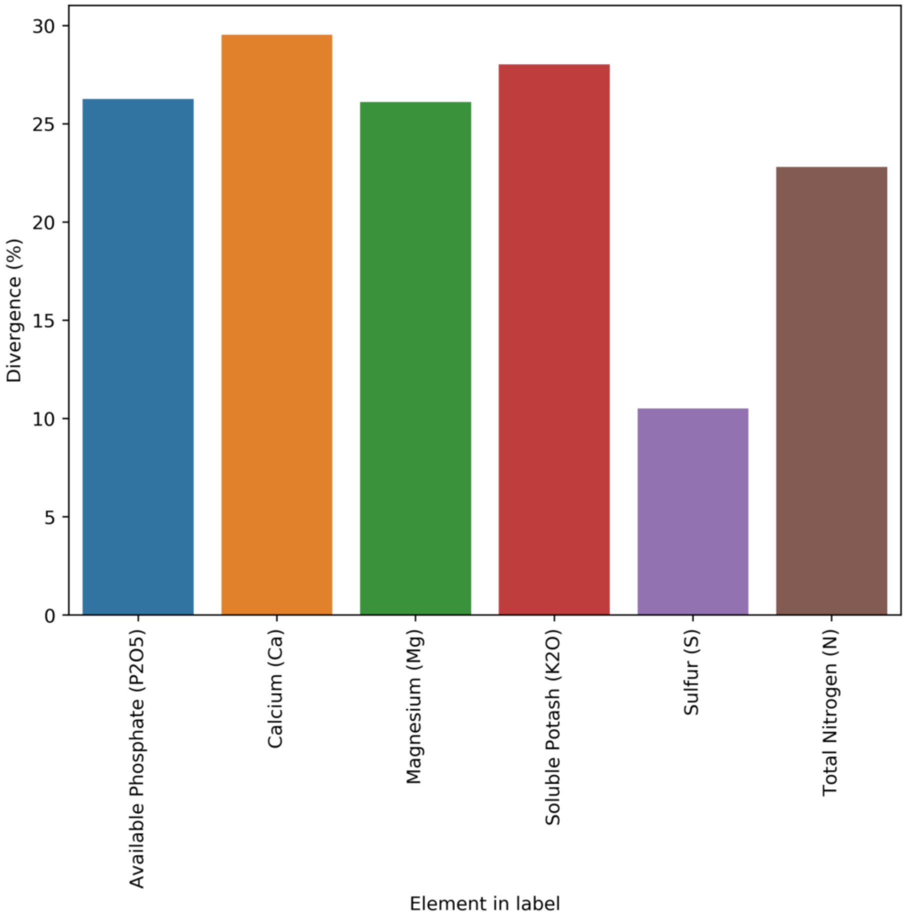
This table shows the precipitated Fe and chelated portions of the micro nutrients in all the standard solutions.

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

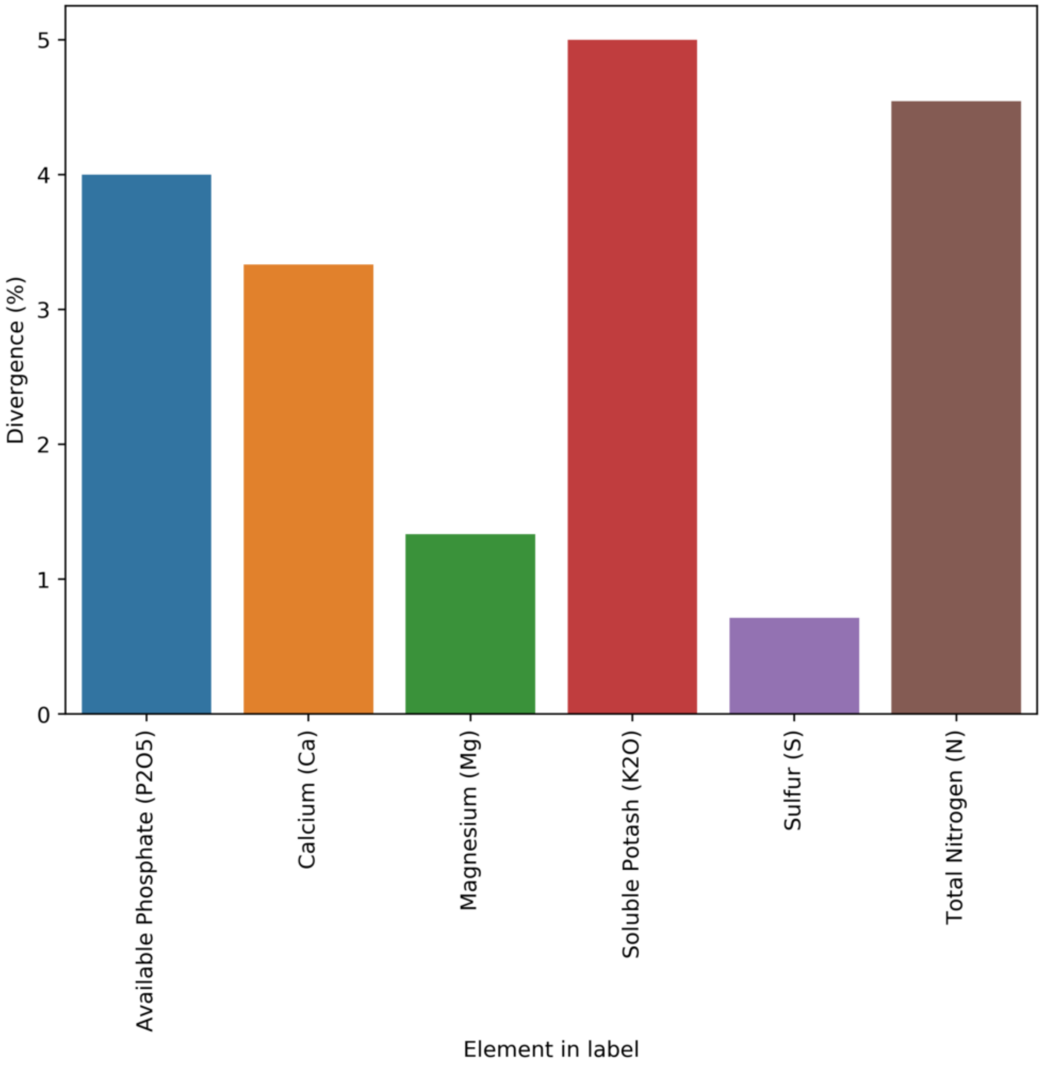
Whenever I am hired to duplicate a company’s fertilizer regime based on commercial products, I always emphasize that I cannot use the labels of the products as a reference because of how misleading these labels can be. A fertilizer company only needs to tell you the minimum amount of each element it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



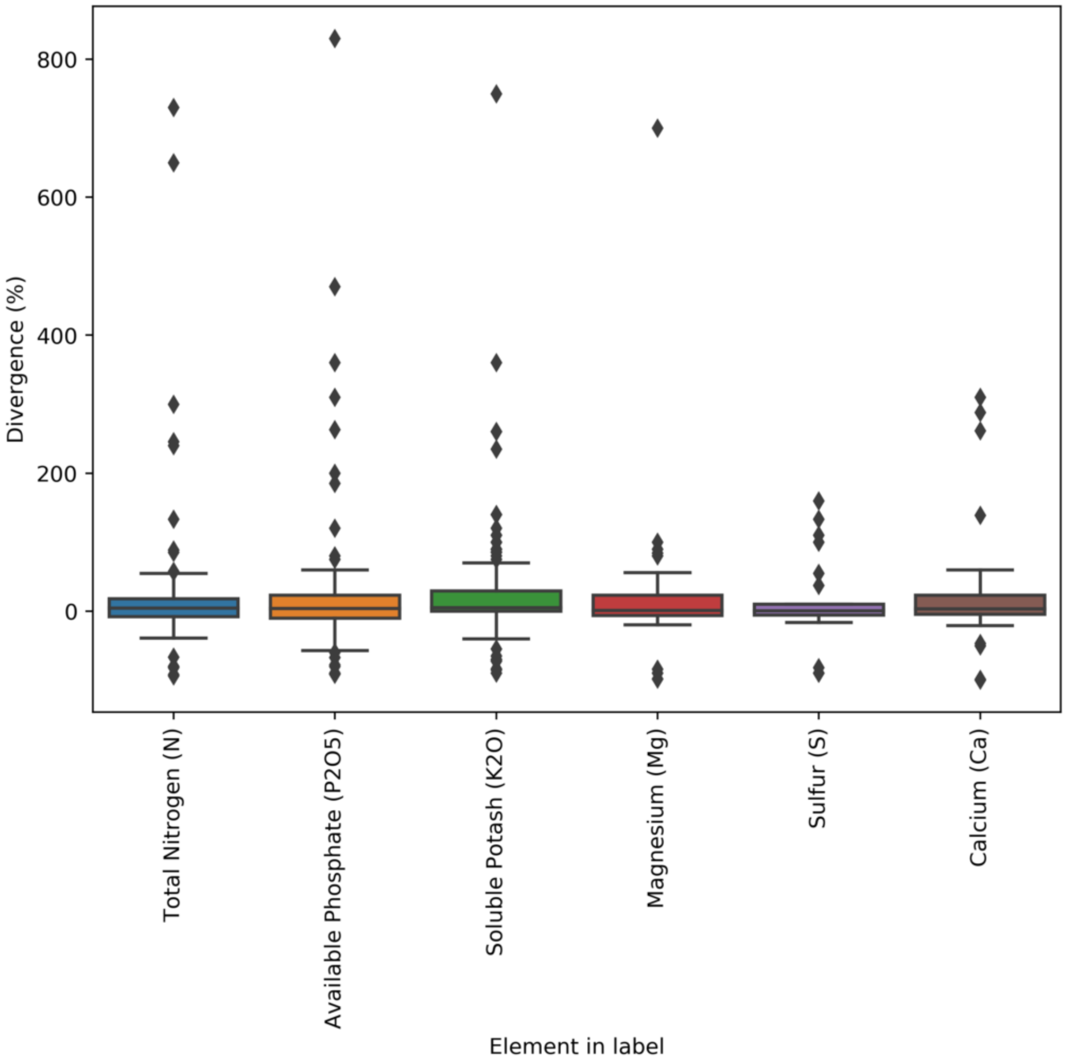
Average deviation from the reported composition on the label compared with lab analysis.

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.