Using a biodegradable iron chelate (IDHA) in hydroponics

Chelates are a very important part of hydroponic nutrient solutions as they provide a reliable source of heavy metals. Without chelates, heavy metals can easily go out of solution and become unavailable, either because they precipitate as an insoluble salt or because they are captured by active surfaces with a high affinity for metals. Among the heavy metals, Fe is the most important to chelate as it’s usually present in the largest concentration and is the most easily taken out of solution by the factors mentioned above.

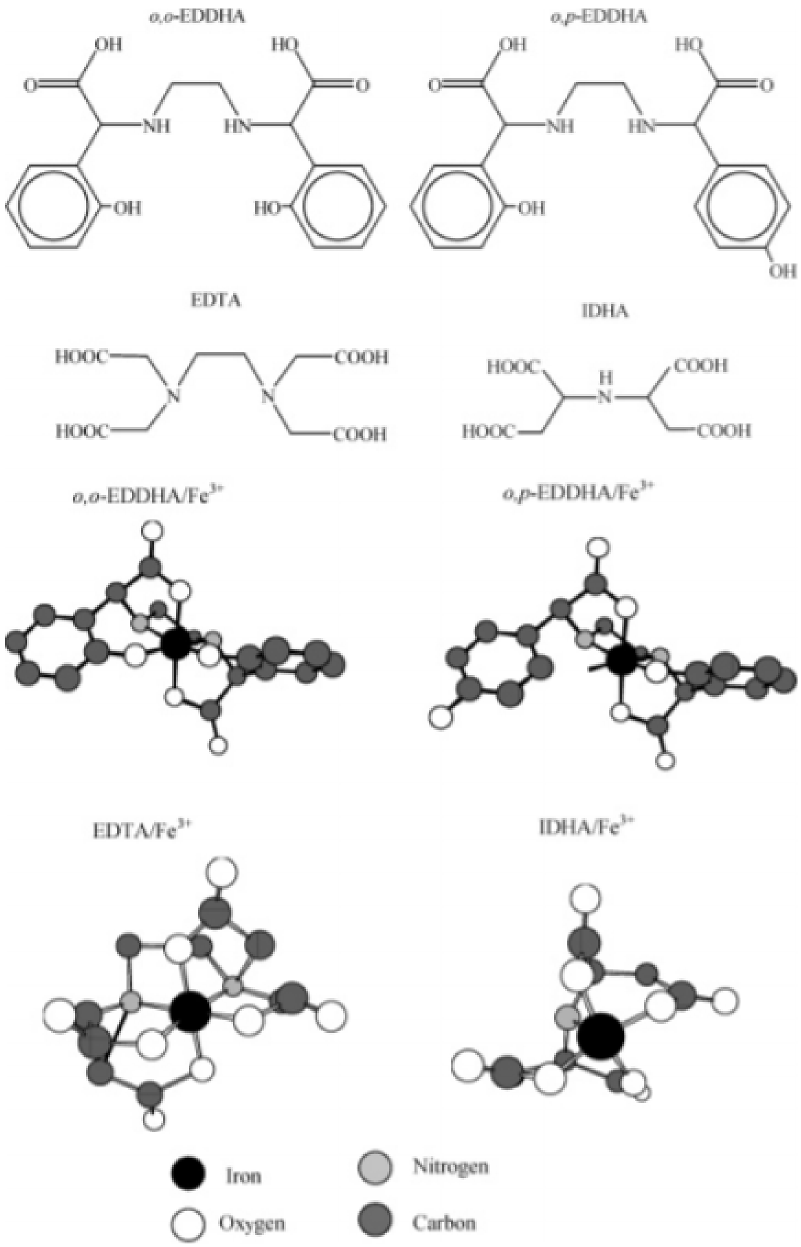


Figure 1. Chelating agents and chelates described in the text.

Models for different Fe chelating agents, taken from [this paper](#).

Commonly chelating agents such as EDTA, DTPA and EDDHA are used in solution and they do a great job in providing adequate supplies of micro nutrients to plants. These three chelators have a very high affinity for Fe and therefore ensure that Fe will remain in solution and available to plants. However, a problem all of these chelating agents share is their lack of biodegradability, they all enter plant tissue and are going to be very difficult to get rid of by the plant. They can therefore accumulate in plant tissues to some extent and can cause problems of their own.

There are however some chelating agents that are both effective at protecting the heavy metals and easily biodegradable, from these, the most largely studied is perhaps imidodisuccinic acid (IDHA) whose structure is showed and compared with the other chelates in the image above. Although this chelating agent shares some common structural features with traditional chelating agents its chemical structure makes it incredibly easy to biodegrade and therefore a nice candidate for fertilizer use.

Fig. 2. Visual aspect of green bean plants development in the experimental greenhouse of the Universidad Autónoma during 2006, after 15 d of treatment.

Fig. 3. Visual aspect of the green bean plants 39 d after the beginning of the treatments. Ethylene diamine tetraacetic acid (EDTA) treated plants suffer from fungus infection while control plants presented typical multi micronutrient deficiencies.

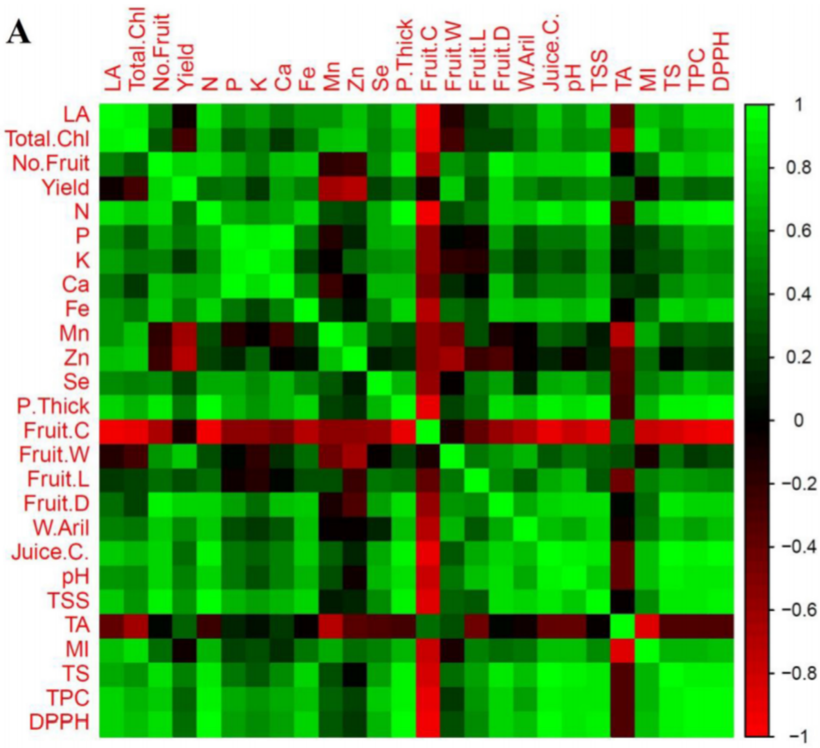
Comparison between EDTA, IDHA and a control, taken from [this paper]

Several papers have compared IDHA fertilization to traditional Fe chelates ([here], [here], [here], [here]). Although the IDHA is usually less stable in solution – as it would be expected given its chemical nature – it tends to give better results in terms of absorption and fertilization compared with the other Fe chelates. Given that it is also completely non-toxic to the plants – while the other chelates make the plant deal with the non-biodegradable aspects – plants fertilized with IDHA can actually be healthier. The image above, showing a comparison with EDTA – shows how the IDHA plants were not affected by a fungal infection that ended up affecting the EDTA treatment.

This does not mean that IDHA is the natural best choice for an Fe chelate. Some of the above studies have shown that IDHA can easily be captured by some media and its lack of stability implies that it is not a good choice for extended use in recirculating systems. However IDHA can be a better choice if the media used allows for it and the grower is able to apply it with its biodegradable nature in mind or if the desired products needs to be free of traditional chelate contaminants. In some cases – as mentioned before – it can actually be a significant improvement over traditional chelates.

Selenium in hydroponic culture

The element selenium (Se) is not commonly used in hydroponic culture – as it's not necessary for plant life – but the fact that it's necessary for human life has meant that plant enrichment with selenium and its effects have been studied in hydroponics. Its effects however, are more than just an increase in Se concentration in plants. In today's post we'll talk about Se and what its effects in plant growth are according to some of the published literature.



Correlation map of all measured plant properties in Se application (from this study)

Different studies can use different forms of Se, so it's important to find out whether a study uses a source of Se cations, like Se chloride or a source of Se anions, like sodium selenate. If you want to reproduce the results you will need to match the exact source used, as using a different source can lead up to completely different results. Most studies focusing on Se use it in concentrations around 0.1 to 0.5ppm, although some studies do go as far as 5-10ppm, especially when studying the effects of the salts where Se is present as a cation.

Although most studies related to Se focus on the fortification of fruits, many studies also measure yield and plant quality related parameters in order to obtain as much information as possible. In this study of Se used in tomato plants there was a substantial enrichment of Se and a delayed ripening but there were no substantial effect on plant growth. However post-harvest characteristics of fruits were significantly improved by Se. Other studies on tomatoes, like this one, have however found improvements in yields when using Se.

Other studies like this one on curly endive or this one using Se nanoparticles in pomegranate, do show significant improvements in plant characteristics from using Se. In the pomegranate study, an 1.35 fold increase in the number of fruits was achieved, a very impressive mark given the characteristics of the treatment.

Plant species	Conc. of selenium as nutrient	Conc. of selenium as toxin	References
Ryegrass (*Lolium perenne*)	1 mg kg^{-1} soil	10 mg kg^{-1} soil	Hartikainen et al. (2000)
Wheat (*Triticum aestivum*)	–	0.2 mg kg^{-1} soil	Tripathi and Misra (1974)
Mung bean (*Phaseolus aureus*)	–	4 and 6 mg L^{-1}	Aggarwal et al. (2011)
White clover (*Trifolium repens*)	–	330 mg kg^{-1} Se in shoot tissue	Mikkelsen et al. (1989)
Rice (*Oryza sativa*)	–	2 mg kg^{-1} in plant tissue	Mikkelsen et al. (1989)
Mustard (*B. juncea L*)	0.5 mg kg^{-1}	–	Singh et al. (1980)
Wheat	1 mg L^{-1}	5 mg L^{-1}	Peng et al. (2001)
Soybean (*Glycine max*)	50 mg L^{-1}	–	Djanaguiraman et al. (2005)
Mung bean	0.5 and 0.75 mg L^{-1}	–	Malik et al. (2012)
Lettuce (*Lactuca sativa*)	0.1 mg kg^{-1}	–	Xue et al. (2001)
Strawberry (*Fragaria ananassa*)	1 mg kg^{-1}	–	Valkama et al. (2003)
Spirulina (*Spirulina platensis*)	≤150 mg L^{-1}	–	Chen et al. (2008)
Soybean (*Glycine max*)	Selenium as seed treatment (5 mg L^{-1}) and foliarspray (100 mg L^{-1})	–	Djanaguiraman et al. (2004)
Sweet Basil (*Ocimum basilicum*)	Foliar spray as 10 mg Se dm^{-3} solution	–	Hawrylak-Nowak (2009a)

Table taken from this review article

Selenium can also be a defense against temperature and salt stress. This article on peppers shows that an application of foliar selenium can help reduce flower drop rates and other adverse effects of temperature stress in these plants. This article on wheat seedlings, shows that selenium can also be protective against salt induced stress, preserving root growth under these adverse conditions.

It is also worth considering that Se can also become toxic to plants at anything but low concentrations. This review, which goes significantly into the articles that had been published up until 2014, goes deeply into this particular issue. The table above is particularly useful, as it shows the ranges of applications and toxicities for some plants. It is within the conclusions of the above review – as we have seen in the articles shown before as well – that Se can be used as an effective additive, stress protector and growth promoter when used in adequate amounts and forms (remember, cationic and anionic forms are different!), while it can become toxic and damaging if used without care.

The use of phosphites in plant culture

Plants normally get most or all of their phosphorous from inorganic phosphorus sources. Most commonly these sources are monobasic or dibasic phosphate ions ($H_2PO_4^-$ and HPO_4^{-2}), which are naturally formed from any other phosphate species at the pH values generally used in hydroponics (5.5-6.5). However these are not the only sources of inorganic phosphorous that exist. Phosphite ions – which come from phosphorous acid H_3PO_3 – can also be used in plant culture. Today we are going to talk about what phosphite does when used in hydroponics and why it behaves so differently when compared with regular phosphate sources. In research P from phosphate is generally called Pi, so I will follow this same convention through the rest of this post. A good review on this entire subject can be found here.

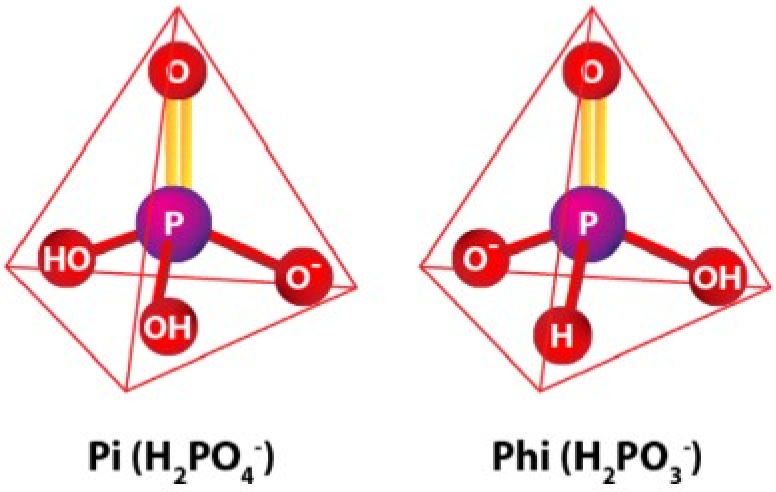


Fig. 1. Three-dimensional chemical structures of phosphate ($H_2PO_4^-$; Pi) and phosphite ($H_2PO_3^-$; Phi) forming tetrahedral structures.

The role that phosphite (Phi) plays in plant nutrition and development has now been well established. Initially several people claimed that Phi was a better P fertilizer than Pi so researchers wanted to look into this to see if Phi could actually be used as an improvement over Pi fertilization. However research was heavily disappointing, studies on lettuce (here) , spinach (here), komatsuna (here) as well as several other plants showed that Phi fertilization provides absolutely no value in terms of P nutrition, meaning that although plants do absorb and process the Phi it does not end up being used in plant tissue to supplement or cover P deficiency in any way. Furthermore there are some negative effects when Phi is used in larger concentrations (as those required for Pi) so it quickly became clear that Phi is not a good fertilizer at all.

Why should anyone use Phi then? Well, research started to show that some of the earlier positive results of Phi fertilization were not because it was covering Pi deficiencies but mainly because it was offering a protective effect against some pathogens. Research on tomatoes and peppers and other plants (here and here) showed that phosphites had some ability to protect plants against fungi with plants subjected to Phi applications showing less vulnerability to the pathogens. However the evidence about this is also not terribly strong and a few papers have contested these claims.

Table 1
Beneficial effects of phosphite (Phi) as a biostimulator in vegetable crops.

Crop	Phosphite source (dosage)	Method of application	Improved trait/s	Reference
Celery	Phosphorous acid	Foliar spray	Yield	Rickard (2000)
Lettuce	Phosphorous acid (50% of total P as Phi)	Nutrient solution in hydroponics	Biomass dry weight, foliar area and P content in the whole plant	Bertsch et al. (2009)
Onion	Phosphorous acid	Foliar spray and soil application	Percentage of jumbo size onions	Rickard (2000)
Potato	Phosphorous acid	Foliar spray	Size and yield of US No. 1 grade potatoes	Rickard (2000)
Potato	Potassium phosphite	Foliar application	Phytoalexin and chitinase content, and yield maintenance	Lobato et al. (2011)
Potato	Potassium phosphite	Sprays applied to seed tubers and foliage	Reinforcement of the cell wall and defense response	Olivieri et al. (2012)
Potato	Potassium phosphite	Liquid solution applied to tubers	Emergence, early growth and mycorrhizal colonization	Tambascio et al. (2014)
Potato	Potassium phosphite	Foliar spray	Chlorophyll content, protection against UV-B light and activation of the antioxidant system	Oyarburo et al. (2015)
Sweet pepper	Phosphorous acid	Drip irrigation and foliar spray	Size and yield of US No. 1 grade peppers	Rickard (2000)
Tomato	Phosphorous acid (50% of total P as Phi)	Nutrient solution in hydroponics	Biomass dry weight, foliar area and P content in the whole plant	Bertsch et al. (2009)

Note: Most studies were based on the application of commercial Phi-containing products without clear indication on the labels of their precise Phi content. Therefore, Phi dosage in the table is only indicated when precise data are available in the cited articles.

Table 2
Beneficial effects of phosphite (Phi) as a biostimulator in fruit crops.

Crop	Phosphite source (dosage)	Method of application	Improved trait/s	Reference
Avocado	Phosphorous acid	Foliar spray	Yield of commercially valuable sized fruit	Lovatt (2013)
Banana	Phosphorous acid (50% P as HPO_4^{2-} and 50% as $H_2PO_3^-$)	Nutrient solution in hydroponics	Biomass dry weight, foliar area and P content in the whole plant	Bertsch et al. (2009)
Citrus	Phosphorous acid	Foliar spray	Yield and acid content in fruits	Lovatt (1998, 1999)
Citrus	Phosphorous acid	Foliar spray	Yield	Albrigo (1999)
Citrus	Phosphorous acid	Foliar spray	Yield	Rickard (2000)
Peach	Phosphorous acid	Foliar spray	Sugar and soluble solids content	Rickard (2000)
Raspberry	Phosphorous acid	Foliar spray	Fruit firmness	Rickard (2000)
Strawberry	Potassium phosphite	Plants soaked and irrigated	Fruit acidity, ascorbic acid and anthocyanin content	Moor et al. (2009)
Strawberry	Potassium phosphite (6.7% of total P as Phi)	Root application through a controlled watering system	Growth of roots and shoots	Glinicki et al. (2010)
Strawberry	Phosphorous acid (30% of total P as Phi)	Nutrient solution applied to the roots	Concentrations of chlorophylls, amino acids and proteins in leaves	Estrada-Ortiz et al. (2011)
Strawberry	Phosphorous acid (20% of total P as Phi)	Nutrient solution applied to the roots	Sugar concentration and firmness of fruits	Estrada-Ortiz et al. (2012)
Strawberry	Phosphorous acid (20–30% of total P as Phi)	Nutrient solution applied to the roots	pH, EC and anthocyanin concentration in fruits	Estrada-Ortiz et al. (2013)

Note: Most studies were based on the application of commercial Phi-containing products without clear indication on the labels of their precise Phi content. Therefore, Phi dosage in the table is only indicated when precise data are available in the cited articles.

Those who say that Phi is not mainly a fungicide claim that positive results are mainly the effect of Phi acting as a biostimulant (here). These groups have shown through research across several different plant species, including potatoes, onions, lettuce, tomatoes, wheat, oilseed rape, sugar beet and ryegrass that foliar or sometimes root applications of phosphites consistently yield some positive effects, meaning that there is a strong biostimulant effect from the Phi that is not related to either P nutrition or a fungicidal effect. A recent review looking at the overall biostimulant effects of Phi (here) shows how researchers have obtained evidence of biostimulation in potatoes, sweet peppers, tomatoes and several other species (the images in this post were taken from this review). The different studies mentioned in the review show increases in quality and even yields across these different plant species (see tables above).

While we know that Phi is not a good source of P nutrition and we know it can help as a fungicide in some cases it is clear now that under enough Pi nutrition Phi can provide some important biostimulating effects. Negative effects from Phi seem to be eliminated when enough Pi nutrition is present so rather than be thought of as a way to replace or supplement P nutrition it should be thought of as an additive that has a biostimulating effect. Phi may become a powerful new tool in the search for higher yields and higher quality, while not serving as a replacement for traditional Pi fertilization.

Five important things to consider when doing foliar spraying

Foliar spraying is a true and tested way to increase yields and prevent issues in plant culture. Both soil and hydroponic growers have used foliar fertilizer applications to increase yields and prevent problems due to nutrient deficiencies during the past 50 years. However there is a lot of mystery and confusion surrounding foliar fertilizer applications, reason why this technique is often applied incorrectly or suboptimally. Today I want to talk about 5 key pieces of information to consider when doing foliar fertilization so that you can be more successful when applying it to improve your crop results and reduce deficiency problems. If you want to learn more about these factors I suggest you read the following reviews on foliar feeding (here, here and here). Second table in this post was taken from this study on wheat.

Foliar fertilization is not root fertilization. A usual problem when doing foliar fertilization is to think that the same products can be used for leaves and roots. When you want to increase your crop yields using foliar fertilization you should definitely not use the same products and concentrations you use for soil. There are for example some chemical substances that you would never want to apply to the roots that have actually shown to give better outcomes in leaves. A good example is calcium chloride which is a huge mistake in root fertilizers but a great choice when doing foliar fertilization.

Foliar fertilizers should generally be much more concentrated. When people apply foliar fertilization they usually apply much lower concentrations because they are afraid of burning leaves. Although this can certainly happen if the foliar fertilizer is badly designed research has shown that the best results are obtained with much higher concentrations than what you generally use for the roots. For example when you apply an iron foliar fertilization regime you generally use a concentration of 500-1200 ppm of Fe while in root applications you only very rarely go beyond 4-5 (most commonly 1-3 ppm). Usually concentrations in foliar fertilizers will be much higher and if the fertilizer is correctly designed this will give much better results. The graph below (taken from the first review linked above), shows some of the most commonly used fertilizer concentrations.

Table 3
Amount of fertilizers and water volume used in foliar spray of macro and micronutrients

Nutrient	Formulation or salt	Kg per 500 liter of water
N	$CO(NH_2)_2$	3–5
N	$(NH_4)_2SO_4$; NH_4NO_3; $(NH_4)_2HPO_4$; NH_4Cl; $NH_4H_2PO_4$	2–3
P	H_3PO_4; others see N above	2–3
K	KCl; KNO_3; K_2SO_4	1.5–2.5
Ca	$CaCl_2$; $Ca(NO_3)_2$	1.5–2.5
Mg	$MgSO_4$; $Mg(NO_3)_2$	3–10
Fe	$FeSO_4$	3–6
Mn	$MnSO_4$	1–2
Zn	$ZnSO_4$	1.5–2.5
Cu	$CuSO_4$	0.5–1
B	Sodium borate	0.25–0.5
Mo	Sodium molybdate	0.1–0.15

Source: Adapted from Fageria et al. (1997); Fageria and Barbosa Filho (2006).

Surfactants are very important (don’t use dish washing soap!). Leaf coverage is very important in foliar applications because you want the fertilizer to be evenly spread across the entire leaf not “clumped” into drops due to surface tension. Many people have trouble with nutrient burn due to bad fertilizer design that causes inadequate leaf coverage. However all surfactants are not created equal and ionic fertilizers are very undesirable for this task due to their interaction with leaf tissue and fertilizers. Due to this reason you should NOT use something like dish washer liquid soap but a proper non-ionic surfactant like a polysorbate. The surfactant will be a very important part of your foliar fertilizer formulation.

Timing is also critical. The time when you do your foliar sprays applications is also very important for optimal results. In general you want the leaf stomata to be open and the vapor pressure deficit to be lower so the best time to do foliar spraying is usually during the afternoon after temperatures have dropped significantly. For most time zones this usually means sometime after 3PM. Doing foliar applications sooner can lead to much larger stress due to a higher vapor pressure deficit – risking burns as well – while doing it later leads to less efficient absorption due to the stomata being closed. If applying the spray at this time is not possible then early morning often works as well. Make sure you measure your daily temperature/humidity fluctuations to ensure you don’t do foliar sprays at a high VPD.

Couple adequate additives for yield increases. Research has shown that while nutrient foliar spraying can enhance yields significantly under sub-optimal root feeding conditions if the root concentrations are already optimal – as in a well managed hydroponic crop – it is hard for simple nutrient foliar spraying to provide a lot of benefit. However there are several biostimulants that are poorly absorbed through the root zone that can give you much better results when used as foliar sprays. Additives like salicylic acid and triacontanol can make sure that your nutrient foliar spray gives you maximum additional benefits.

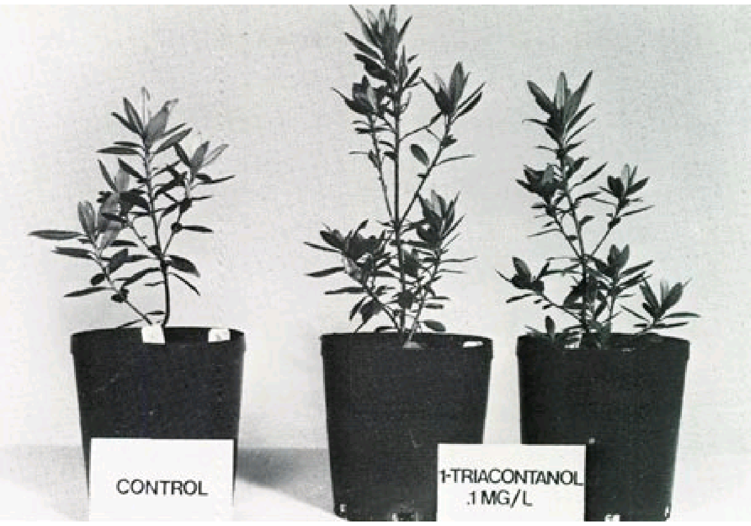
As you can see there is a lot to the design of an adequate foliar spray. You must consider that the substances you use need to be fit to the purpose – not necessarily the same as for root applications! – and that your concentrations, surfactants, additives and application times are adequate. Now that you are aware of these factors you should take them into account when designing your next round of foliar spraying for your crops.

Using triacontanol to increase yields in hydroponics

Usually additives used in hydroponics need to be added in rather large quantities to obtain palpable results. Molecules like salicylic acid – which we have discussed before

– need to be used in concentrations in the order of 10^{-4} to 10^{-2} M to obtain a significant effect. This means that you need to use quantities in the order of 20-150ppm of most additives in order to see a significant result. However there is a molecule called 1-triacontanol that can generate very significant results with only a fraction of that concentration. Today we will talk about this substance, what it does, how to use it and why it's such a desirable tool in your hydroponic additive arsenal. Many of the things I will talk about in this article are derived from [this 2011 review] on triacontanol (make sure you read that for a deeper insight into why this molecule works).

–



–

Triacontanol is a very long fatty alcohol. Each molecule has 30 carbon atoms linked in a linear structure which makes this molecule extremely hydrophobic and hence very hard to dissolve in something like water. Using triacontanol therefore involves dissolving this molecule in something other than water – for example Tween 20, chloroform, methanol – before adding water in order to prepare an emulsion for use in either root applications or foliar feeding. Most research using triacontanol has used foliar feeding as this is the easiest way to control the application of the molecule and also how it seems to have the largest effect.

The effects of this molecule are not short of miraculous. Triacontanol is usually applied in concentrations on the order of 10^{-7} to 10^{-9} M, which means it is used from around 0.01 to 1 ppm. This means that we use about 1000 times less triacontanol than other additives in order to obtain a meaningful result. The table below shows some of the effects that triacontanol has showed in peer reviewed studies, with plant height, weight and yields increasing across a variety of different species, from tomatoes to japanese mint. Papers on other plants besides those on the chart have also been published, for example triacontanol has showed to significantly increase yields in lettuce crops ([here](#)). Some studies have also found that the effect of triacontanol can also be enhanced through the use of magnesium or in conjunction with other hormones ([here](#)).

_

Table 1 Positive response of various plant species to foliar application of triacontanol.

Name of plant	Botanical name	Family name	Growth attributes	Yield attributes	Biochemical attributes	Quality attributes	Reference citation
Opium poppy	*Papaver somniferum* L.	Papaveraceae	Plant height, dry weight and number of branches	Number of capsules, seed yield per plant, and crude opium yield per plant	Chl *a*, Chl *b*, and total content	Morphine content and morphine yield per plant	Khan et al. (2007)
Tomato	*Solanum lycopersicum* L.	Solanaceae	Height per plant, number of leaves and plant fresh and dry weights	Number of fruits per plant, weight per fruit and fruit yield per plant	Total chl and carotenoids content, leaf-N, -P, and -K contents	Fruit ascorbic acid and lycopene contents	Khan et al. (2009)
Hyacinth bean	*Lablab purpureus* L.	Fabaceae	Plant fresh and dry weights, leaf-area per plant, number and dry weights of nodules	Number of pods per plant, number of seeds per pod, 100-seed weight and seed-yield per plant	Photosynthetic rate (P_N), stomatal conductance (gs) and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, -K, and -Ca content, nodule-N and leghemoglobin contents	Seed-protein content, total carbohydrate content, and tyrosinase activity	Naeem and Khan (2005), Naeem et al. (2009)
Artemisia	*Artemisia annua* L.	Asteraceae	Shoot and root lengths, plant fresh and dry weights	Artemisinin yield	P_N, gs and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, and -K content	Essential oil content, artemisinin content	Aftab et al. (2010)
Coriander	*Coriandrum sativum* L.	Umbelliferae	Shoot and root lengths, plant fresh and dry weights		Total chl and carotenoids content, NR and CA activities, leaf-N, -P, and -K content	Essential oil content	Idrees et al. (2010)
Coffee senna	*Senna occidentalis* L.	Fabaceae	Plant fresh and dry weights	Number of pods per plant, number of seeds per pod, 100-seed weight and seed yield per plant	P_N, gs and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, -K, and -Ca content	Total anthraquinone and sennoside contents, and seed-protein content	Naeem et al. (2010)
Sweet basil	*Ocimum basilicum* L.	Labiatae	Shoot and root lengths, number of spikes per plant, total leaf area, plant fresh and dry weights	Essential oil yield	Chl *a*, Chl *b*, total Chl, and carotenoid contents, activities of NR and CA, leaf-N, -P, and -K contents	Leaf-protein and carbohydrate contents, essential oil content, linalool, methyl eugenol, and eugenol contents	Hashmi et al. (2011)
Japanese mint	*Mentha arvensis* L.	Lamiaceae	Plant height, leaf-area, leaf-yield, and plant fresh and dry weights	Herbage yield, essential oil yield	Total chl and carotenoid contents, activities of NR and CA, leaf-N, -P, and -K contents, total phenol	Essential oil content, menthol, L-menthone, isomenthone, and menthyl aceteate contents	Naeem et al. (2011)

Abbreviation: Chl, Chlorophyll; NR, Nitrate reductase; CA, Carbonic anhydrase.

–

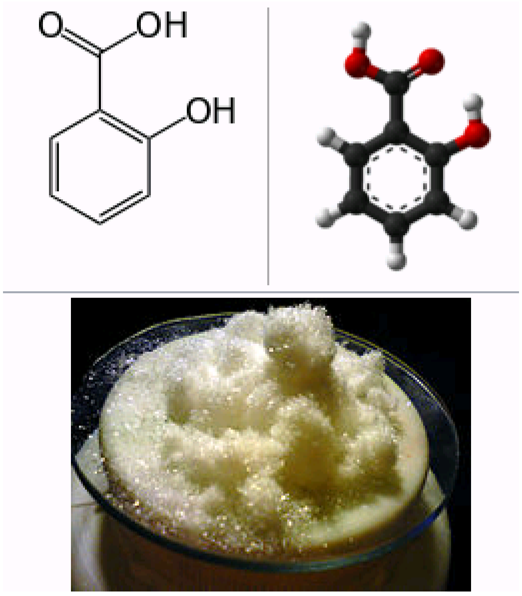
With such an impressive array of effects and such a low expected toxicity – due to its very low solubility – it’s definitely one of the best additives to use to get production gains in hydroponic crops. This also makes it one of the most commonly used substances in commercially available grow enhancers. Nonetheless since it’s used in such a small quantity it’s very easy for someone to buy a small amount of triacontanol and use it for years before running out. You can buy small amounts of triacontanol as a powder (there are several reputable sellers on ebay) and you can then prepare your own concentrated triacontanol solution in Tween 20 – not water – that will last you for ages. A liter of 2000ppm solution of triacontanol will last you for 1000-2000 liters of foliar spray. You cannot get more economical than that.

The optimum application rate and frequency for triacontanol varies across different species but if you want to take an initial guess use a foliar application of a 0.5 ppm solution every week. There is usually a sweet spot for concentration – after that you start to see a decrease in results compared to the highest point – so you want to start below a 1 ppm application rate. For some crops repeated applications might be unnecessary – with just one or two applications giving most of the effect through the entire crop cycle – while for others you do want to apply every week. How you initially dissolve the triacontanol to make your concentrated solution is also important with Tween 20 being the most ecologically friendly – although not the easiest – option.

Salicylic acid and its positive effect in hydroponics

When looking for ways to increase crop yields we usually want something that is safe for the environment, safe for us and able to give us a substantial bang for our buck. From the multitude of additives that have been researched during the past 30 years one simple organic molecule seems to fit all the requirements very well: salicylic acid. Today we are going to talk about why this additive is so interesting for use in hydroponic culture, the results it has shown in peer reviewed publications and how we can use it to increase our crop yields. For those of you interested in this molecule I would also recommend reading [this 2010 review] which contains a much more detailed look into the scientific literature surrounding salicylic acid research in higher plants.

–

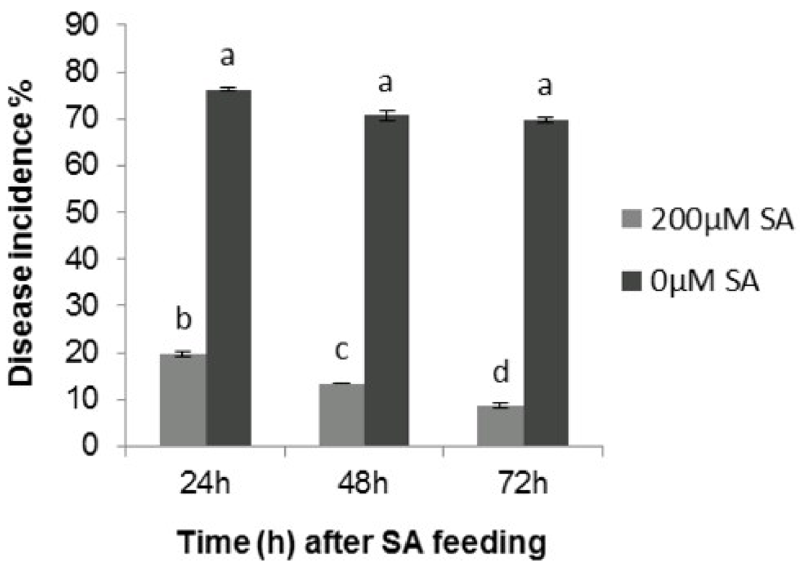


–

Salicylic acid is a simple organic molecule with the structure showed above. We have known for a long time that plants produce it and we knew almost right from the start that it played a key role in plants' response to diseases and stress (see here for some early insights from Tobacco cultivation). Salicylic acid is used as a signaling molecule in plants (a.k.a hormone), moving from stressed organs to non-stressed ones as the plant is attacked. However its role is much more complex, having functions related with chloroplast creation, inhibition of fruit ripening and many other important processes.

After learning that this was an interesting molecule it wasn't long before people started studying whether exogenous applications provided any benefit. We have learned that it enhances dry mass and leaf area in corn and soybean (here), that it can enhance germination in wheat (here), the oil content in basil (here), the carbohydrate content in maize, etc. There are also several studies pointing to improvement in root development – even from foliar applications (here) – suggesting that this hormone is able to increase plant productivity through several different mechanisms. The incidence of diseases can also be reduced dramatically by salicylic acid applications (here).

–



—

We also know this molecule has important effects on the flowering process. It can induce earlier flowering in plants and can often cause larger fruit settings in some plants (like papaya (here)). Most importantly foliar spraying of tomato and cucumber plants with salicylic acid has showed important increases in yields (here). It is therefore clear that exogenous applications of salicylic acid can have many important benefits in crop production and this is therefore an important candidate to consider for enhancing crop production.

But how do we apply it? Most commonly this molecule is applied in foliar feeding regimes, although in some cases it is also applied directly in hydroponic solutions. Most commonly concentrations in the order of 10^{-5} -10^{-4} M are used since it has been showed across a few studies that negative effects start to show up when the concentration level reaches 1mM. This means that regular doses will be around 1-100 ppm with the lowest spectrum of dosage being preferred if the effect on the particular plant is unknown. The solubility of salicylic acid is 2.48g/L at 25°C so concentrated solutions of up to around 20-30x can be prepared without issues to make it easier to apply on plants. The preparation of more concentrated solutions requires some tricks but it certainly can be done.

—

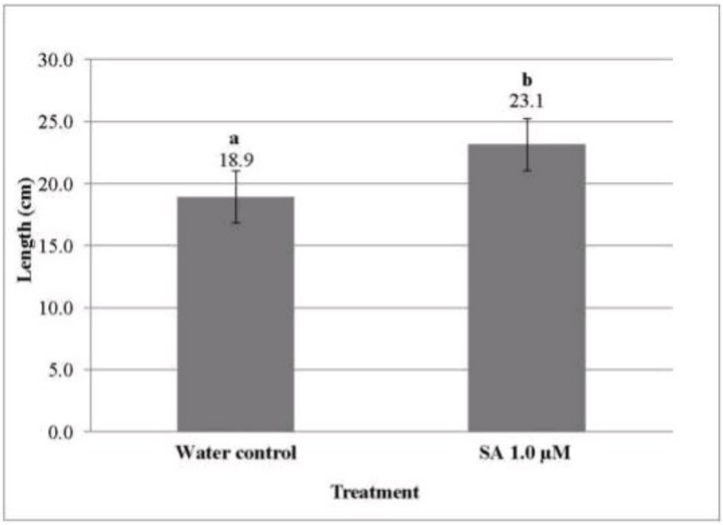


Figure 2. Effect of the spray application of 1µM of Salicylic Acid on the length of *Brosimum alicastrum* seedling stems. The average of 6 repetitions ± standard error is shown. Similar letters indicate no significant difference (Fisher, $p \leq 0.05$).

Salicylic acid also has the advantage of being a very safe molecule so it can be applied without a lot of worry in order to experiment with its effects. For testing on new plants foliar applications of 20-30ppm would be most common, with applications usually carried out once every 5-10 days. The frequency of application as well as the best concentration to use will of course depend on the particular plant you're growing. There are also several other molecules that can be used with salicylic acid to enhance its effect on some plants, but this will be the focus of a future post.

Finally it is also worth noting that ***salicylic acid is not aspirin*** (aspirin is acetylsalicylic acid, a related yet different molecule) so if you want to experiment with this additive you should buy salicylic acid instead of just "dumping some aspirin" into your foliar or hydroponic nutrient solution.

Using titanium to increase crop yields

There are many additives that can be used to enhance the yield of flowering crops. Some have been covered in this blog – like silicon – while others haven't been mentioned here. Today we are going to talk about a rarely discussed additive that is infrequently used in plant culture these days: Titanium. I want to talk about this additive in light of a literature review that came up recently (April 2017) about the use of Titanium in crop production. The magazine where this review came from (Frontiers in Plant Science) is a magazine that often has good content in the field of innovative crop enhancing techniques.

–

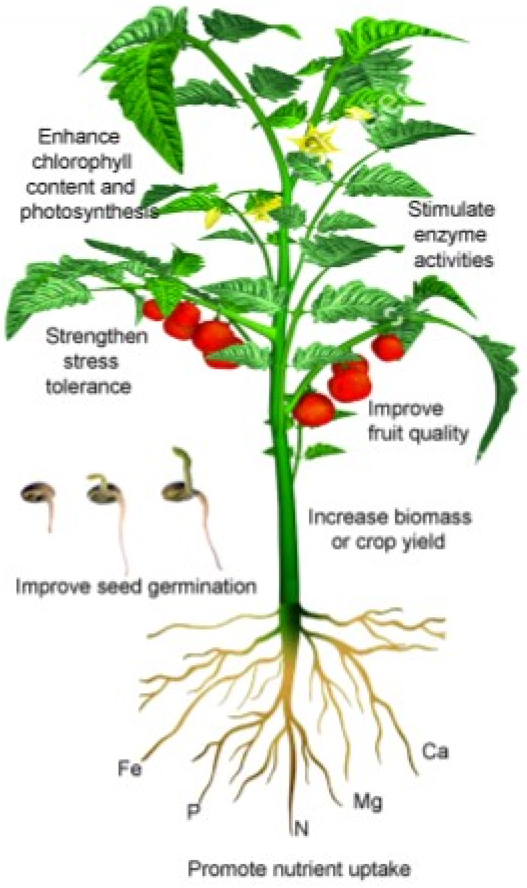


FIGURE 1 | A schematic illustration of Ti effects on crop performance. Ti applied via roots or leaves at appropriately low concentrations has been shown to promote seed germination, enhance root uptake of other nutrient elements, stimulate the activity of some enzymes, increase chlorophyll biosynthesis and photosynthesis, strengthen stress tolerance, and improve crop quality and yield.

–

Titanium use in plant culture is not new. From the early 1980s people started to experiment with titanium as techniques were developed in order to produce titanium chelates that could be used in foliar applications. Basically all reports of yield increases – that show wonderful increases up to even 95.3% in yields – come from a paper on the biological importance of titanium by Dr. István Pais in 1983 and then another publication in 1991 by the same person (here). Other authors have also showed increased yields (here and here) although in some cases in conjunction with other additives (like Si) with results often much less dramatic than the initial 1983 papers. Titanium nanoparticles have also been tested and their effect has mostly been negative with decreases in plant growth and often DNA damage. For this reason when using titanium you want to go with a soluble chelate and not nanoparticle sources.

Creating aqueous stable Ti is not a cake walk. There is currently only one product that carries water soluble Ti (called Tytanit) and as far as I can tell no other commercial products for the application of Ti exist at this moment. This tytanit product is most probably titanium ascorbate – the most popular chelate used – but other organic chelates, like Ti citrate, might be usable as well. Preparing Ti ascorbate is not so easy to get as well – you cannot just buy it on ebay/alibaba as it's not stable as a solid – so you need to prepare it from scratch. Titanium chemistry in solution is sadly very complicated.

However there is probably a route to the easy preparation of such complexes using a simple method involving titanium dioxide and ascorbic acid. We know from dissolution studies of titanium dioxide that it can be dissolved significantly by ascorbic acid but the final concentration of these solutions is not very high with a final concentration of around 0.025M of Ti possible in solution using this method, with a surrounding concentration of 0.15M of ascorbic acid. More acid does not help dissolve more titanium dioxide as this seems to be the solubility limit of the titanium complex. This gives you around 1.2g/L of Ti which you need to dissolve 500-1000x to arrive at the recommended application rate of 1-2 ppm. This will give a final ascorbic acid concentration of 26ppm which is acceptable as an additive as well.

Obviously there are some further formulation steps necessary to get the above to work correctly but this outlines the basics to develop a concentrated titanium ascorbate product that can be used for the creation of a Titanium supplement. Industrally this can be achieved much more efficiently with the use of titanyl sulfate which is a readily soluble and easy to get industrially – but hard to get for your home – form of titanium. You can see this patent for examples of how a fertilizer using titanyl sulfate can be prepared.

Evidence about titanium – applied as titanium ascorbate in a foliar spray – being positive for crops is significant. Various positive effects have been shown across a significant variety of plants across several different plant types – tomatoes, beans, peppers – by different authors. The effect on yields is not so clear – probably in reality not as large as shown in the original studies, but probably significant enough to warrant further studying. The development of low-cost processes for the manufacturing of titanium fertilizers will further enhance their use and increase our knowledge about their true capabilities. More studies with ascorbic/ascorbate controls will also show us clear evidence of whether we are seeing effects related with the ascorbate or the actual Ti chelate.

What is the effect of amino acids in hydroponics?

It is very common for hydroponic nutrient manufacturers to add amino acids to their products. They often mention significant benefits that range from strengthening plants to greatly increasing yields or product quality but they rarely mention any peer reviewed evidence studying these effects. Today we are going to look at the use of amino acid applications in hydroponic culture and the effects that amino acids have been shown to have when used in a variety of different crop types. We will see some of the benefits and the problems that they have shown to cause as well and we'll discuss whether it is actually worth it to apply them in a hydroponic nutrient solution.

–

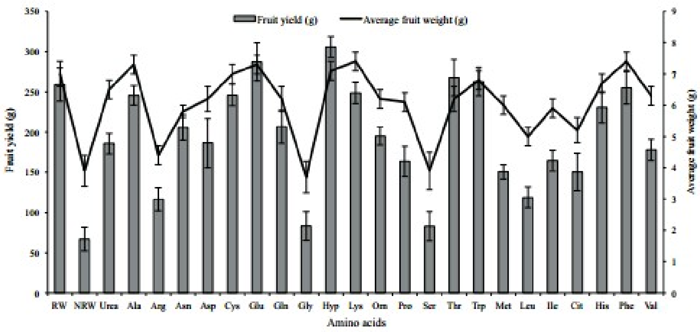


Fig. 3. Effect of twenty two amino acids on the yield of strawberry plants grown in non-renewed nutrient solution in closed hydroponic system. RW: renewed, NRW: non-renewed, amino acids are presented as their three letters abbreviation.

—

Amino acids – which I am going to use here to refer to L-alpha amino acids – are basically organic molecules that are used as the basic block for protein construction in all life forms. Plants are able to synthesize all the amino acids they need internally while in the case of animals many of these amino acids need to come from other animal or vegetable sources. However since amino acids can be added to nutrient solutions and plants can absorb them (see here) it is interesting to wonder what the effects they might have.

There are two ways in which amino acids can affect a hydroponic crop. They may be absorbed and used directly by the plant or they may create a chelate with a metal ion and affect that metal's absorption. It is very difficult to separate both effects – except when specific metal absorption studies are carried out – so the effect on yields is generally a combination of these two. The specific amino acids used and their proportion are also critical to these effects as both plant absorption and the stability of metal chelates depend on the exact structure of the amino acids in solution.

There is significant evidence that amino acid applications reduce nitrate assimilation (see here, here and here) this is not surprising given that amino acids compete with nitrate in the nitrogen cycle and may be more readily assimilated by plants. This seems to be especially the case if nitrate concentrations are low and the plants are N deprived. The effect is most important for glutamine, not surprising as glutamate synthesis is basically the mechanism used for ammonium incorporation by plants.

—

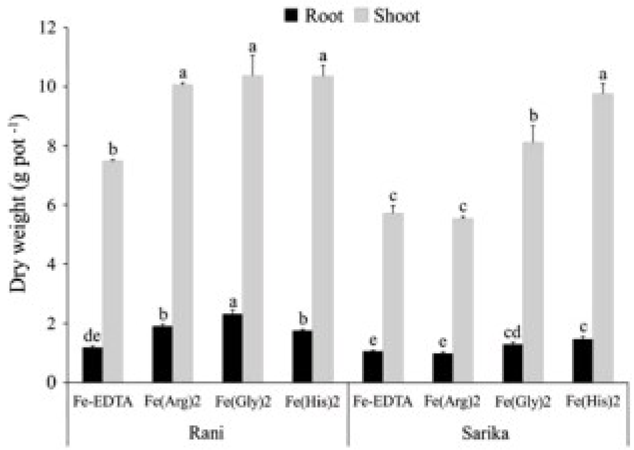
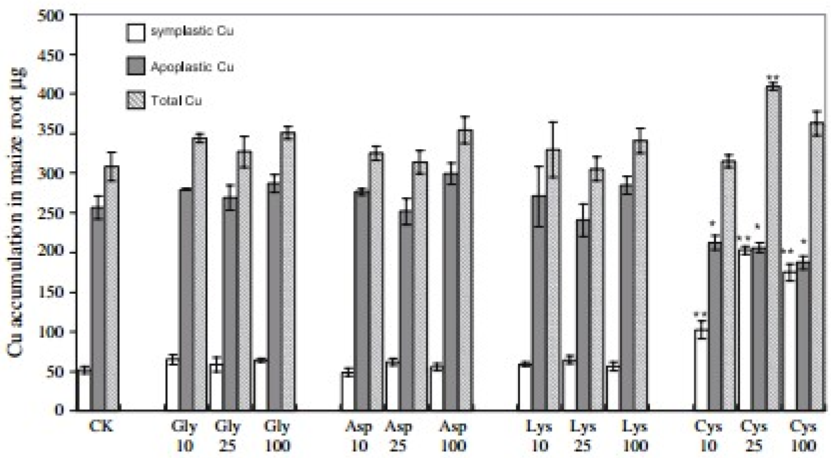


Fig. 1 Root and shoot dry matter weights of two tomato cultivars grown in nutrient solution containing Fe-EDTA, Fe-arginine [$Fe(Arg)_2$], Fe-glycine [$Fe(Gly)_2$], and Fe-histidine [$Fe(His)_2$]. *Error bars* represent standard error ($n = 3$). *Bars* having different letters in root or shoot are significantly different at the 5% level by LSD



—

There is also evidence that amino acids can help plants under stress conditions. For example strawberries in autotoxic conditions – meaning that they have made a nutrient solution toxic after a lot of recirculation – benefited greatly from an amino acid cocktail application (here) and Canola plants have shown to have increased yields under saline conditions with proline applications (here). Plants under heavy metal stress can also benefit from the presence of amino acid, for example rice seedling have shown to benefit from amino acid applications under cadmium stress (here).

There are also limited studies in the use of amino acids as metal chelates in hydroponics. A 2012 study (here) compared different Fe chelates with Fe EDTA and showed that some of these chelates work better than the traditional EDTA chelate in Fe absorption. Fe glycine showed the best absorption across roots and shoots plus the best yields in tomatoes (second image in this post). This shows that Fe glycine may be a good candidate for the replacement of Fe EDTA in hydroponic solutions. Another study (here) also compared different Cu containing amino acid chelates and found that cysteine may be effectively used for Cu fertilization and phytoremediation.

Is it worth it to apply amino acids in hydroponics? This may depend on the exact conditions the plants are facing. While amino acids have proved beneficial for the assimilation of specific nutrients – like Fe and Cu – or the alleviation of some stress conditions (salinity, autotoxicity), there isn't any strong evidence suggesting wide range beneficial effects under normal plant growing conditions, especially if these are close to ideal. In normal hydroponic solutions introducing large amounts of amino acids may even have significant negative effects due to their effect on ion absorption and N metabolism. Further evidence is required before general recommendations for exogenous amino acid applications can be made.

This doesn't mean that amino acids might not be beneficial under normal conditions, just that we have no evidence yet showing which amino acid profiles might work best for which plants and under what concentrations and we do know that there can be potentially harmful effects if these parameters are not studied carefully.

Some things you should know about sodium in hydroponics

Sodium is a ubiquitous element, you can find it in your tap water, in the sea and in most eatable foods. It is also necessary for animal life where it plays a key role in many biological processes. However – despite its overwhelming abundance – sodium is in fact not required for plant life in general (although some species, like C4 plants, do require it in small measure), meaning that it can act in a detrimental manner when present in significant quantities in hydroponic culture. Today I want to talk about what problems sodium can cause, how they can be attenuated and how we can deal with it in hydroponic crops.

–

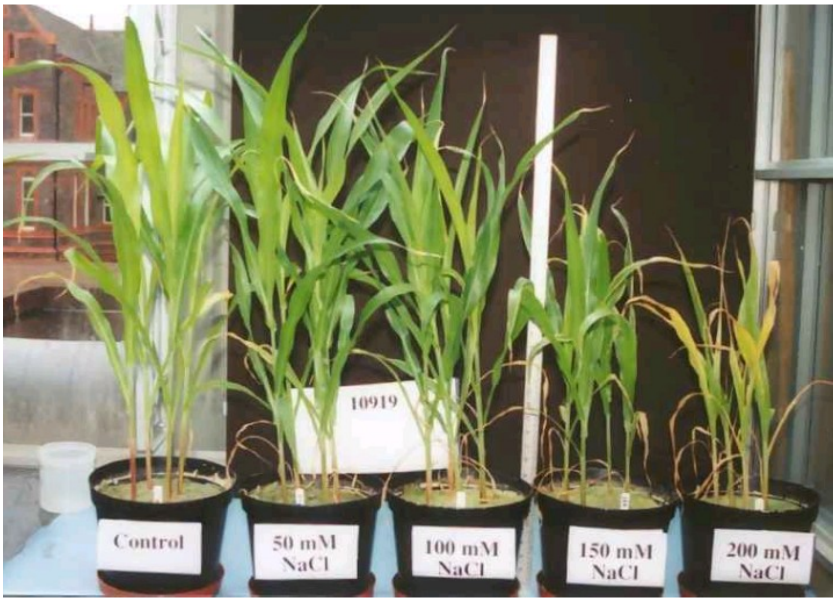
–

So what is the problem with sodium? Sodium in its cation form (Na+) is an extremely soluble ion with an ionic radius that is intermediate between those of lithium and potassium. Being from the same group it chemically behaves in a similar way to these two elements and can therefore act in a similar manner when in contact with plants. Sodium – when present in large enough quantities – will enter plants in significant quantities and replace potassium in some biological roles. Although this might work in your favor when potassium is scarce it does not replace it very well and ultimately costs you dearly in terms of plant growth when compared to plants grown without sodium. You can read this 1976 review for some good information about some general effects of sodium on plants.

Since sodium is so ever-present it is a significant concern in agriculture. This is a reason why there are so many salinity studies – which is what the abundance of salts like sodium chloride is usually called – often aimed at finding ways to attenuate the effects of sodium to make plants grow effectively under high salinity conditions. This is not because people will add things like table salt to agricultural crops but because many areas around the world simply don't have a choice and need to deal with higher salinity conditions. Things like additives, substrates, irrigation cycles and light treatments are investigated to figure out how they affect plant behavior under these conditions. For example this recent study sought to find out if silica nano-particles could help with this problem (and they do!).

In your hydroponic crop sodium might be an important concern in two main ways. The first is if your water source contains a significant amount of sodium. In general sodium starts to be worrisome above 5 mM which is around 120 ppm which is the point where it can start to significantly affect yields and growth. However sodium even at 12 ppm can start having some micro-nutrient like effects, but these can be mostly beneficial in flowering plants like tomatoes and peppers, even increasing fruit quality when given in moderation (see here). However many plants are resistant to even moderate levels of sodium if these are not kept for too long so if your source water has something like 20-60 ppm of sodium (common in the US), you shouldn’t really worry too much about it. In reality huge problems usually start at around 75mM of NaCl which is closer to 1725ppm of Na, although with some Na sensitive crops this might be much lower (like lettuce where 100ppm is already very detrimental to growth).

–



–

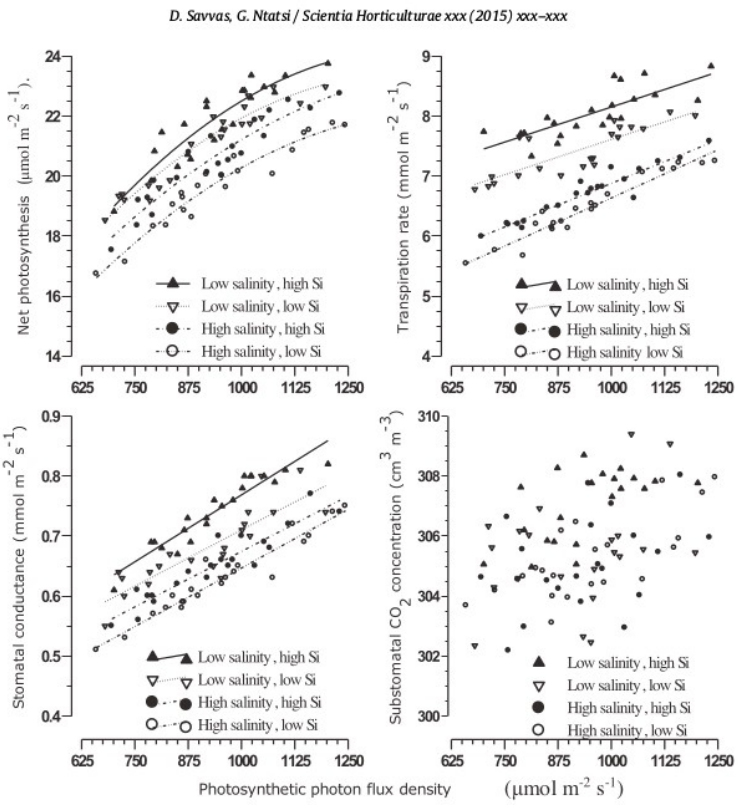
The second problem you might face only happens if you have a system that recirculates nutrient solution. Since sodium is not absorbed so readily by plants it can easily accumulate in a nutrient solution that is recirculated for a significant period of time. During one month of operation a 1 gallon per plant deep water culture system can increase the concentration from tap water 5 fold. This presents a problem since this implies that a hydroponic system that initially had 50 ppm of Na can easily end up with 250 after a single month of solution recirculation. This poses a limit to the life of a nutrient solution, even if other nutrient concentrations are adequately controlled through routine lab analysis. This means that if you want to keep solutions for longer than a few weeks you probably need to use reverse-osmosis water to avoid this problem – although more about the issue of solution life in a future post.

In the end sodium is an element that might be good to have in small measure in most cases, if you are growing C4 plants – like maize or sugar cane – then it is essential in a small amount (20-60 ppm) but you will want to avoid having sodium in any bigger amount or it can start to affect your growth. For plants where sodium isn't biologically necessary it can still provide some useful supplemental roles but in this case it might be best to keep it close to micro-nutrient levels, at 5-15 ppm. However if you are growing a halophilic plant – like say swiss chard – then you might want to have even more than 1000ppm of sodium to increase your growth (see here).

Is ortho-silicic acid worth the additional expense in hydroponics?

Silicon is all the rage right now and different silicon product manufacturers are racing to produce commercial products that contain more and more biologically active silicon. The idea is mainly that potassium silicate – the most commonly used form of silicon in hydroponics – has some problems maintaining high bioavailability at the pH levels used in hydroponics and therefore more stable silicon sources are needed to meet plant needs. However we need to ask ourselves if this is actually true and whether it is actually worth it to go to much more expensive Si sources when supplementing plants with silicon products. Today I want to talk about the Si research up until now and what it tells us about silicon and stabilized silicon products.

–



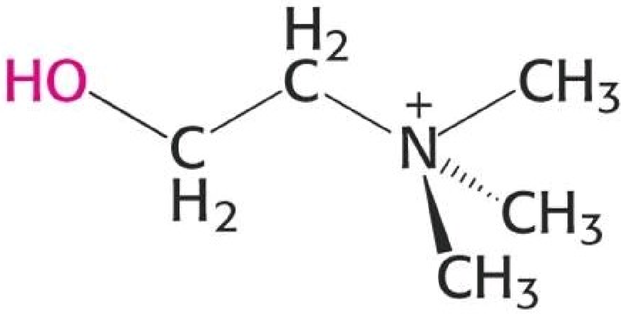
–

Without a doubt there are some proven benefits to using silicon supplementation. As explained within [this recent literature review] from 2015 about silicon's role in plants the benefits from silicon application include increased photosynthesis, resistance to abiotic stress as well as increased resistance to several fungal pathogens. It is also clear that foliar application of Silicon does not lead to large increases in tissue concentration and root applications tend to yield the biggest benefits. The above image shows some of the benefits of high (1mM) and low Si (0.1mM) treatments under different conditions for hydroponically grown Zucchini plants. The review also mentions the exploration of stabilized silicon forms and the current lack of scientific evidence regarding their efficacy when compared with traditional non-stabilized forms of silicon.

_

So if silicon from potassium silicate can show benefits why may we need a better form of silicon? The problem with silicates is that under low pH values the silicate ion gets protonated and converted into silicic acid but silicic acid is unstable and will tend to polymerize and form molecules with limited bioavailability under these conditions. If we use a form of silicon that does not suffer from this problem then we might be able to get some additional benefits. There are indeed a few studies in lettuce and tomatoes showing that choline stabilize orthosilicic acid (ch-OSA) can indeed improve plant responses under Mn stress and even a study about the use of ch-OSA improving seedling growth but these results lack controls against potassium silicate so we don't know if the response would simply be equal than that of a traditional silicate application. Below you can see a graphical representation of a choline molecule's structure, choline is basically a beta aminoacid that is able to stabilize silicic acid by binding to its oxygen atoms through the positive trimethyl amine group, inhibiting polymerization.

_



Choline

—

We know however that not all forms of stabilized silicon sources would work well. For example there is a study involving alkyl silicic acids (another form to stabilize silicon) that shows that the application of these compounds produces even worse results than controls with no silicon supplementation. Plants do not seem to deal well with this type of stabilized compounds, where the silicon is stabilized by the introduction of simple alkyl groups. Some of these forms of silicon – dimethyl silicic acid – were even highly toxic to plants at low concentrations.

—

Up until this point there is basically no scientific evidence that shows how stabilized silicon sources like ch-OSA may provide a benefit over using a simpler and cheaper source of silicon like potassium silicate in higher plants. If potassium silicate is dissolved at the appropriate concentration and in an adequate manner then there is no doubt that it can provide significant benefits at a fraction of the cost. Companies producing ch-OSA and similar silicon stabilized sources generally say that they contain “more bioavailable silicon” and while it may be true that they may allow for the larger abundance of some silicon species in solution, what they should show is an increase in benefits when compared with a potassium silicate control since this is in the end what interests most hydroponic growers. While this evidence is lacking it is certainly not worth it to pay the extra cost, given that benefits using potassium silicate have been proven while benefits using ch-OSA haven’t been proven to be greater than those obtained with these cheaper Si sources.